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ABSTRACT

This thesis examined variations in the word decoding skills of children with reading disabilities. These variations were related to possible cognitive, developmental, and environmental causes of reading disability. Possible implications for educational interventions were also analyzed in the five studies. The thesis critically examines the inclusion of the concept of intelligence in the definition of developmental dyslexia. It is suggested that variations in word decoding skills should offer a more solid basis for a study of varieties of reading disability. The empirical studies showed that: (1) in young children there was a shift from phonological to orthographic word decoding; (2) phonological type children (weak in phonological decoding) were characterized by specific phonological deficits; (3) surface type children (weak in orthographic decoding) showed more global cognitive deficits suggesting a general developmental delay; (4) surface type children showed impaired visual implicit memory for words, which might be associated with limited print exposure; (5) an improvement in phonological awareness only transferred to an improved text reading ability for some children with reading disabilities; and (6) children who did not benefit from a phonological intervention seemed to rely on orthographic word decoding in text reading. (Each of the five studies contain references.) (CR)

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Studies from the Swedish Institute for Disability Research No. 1

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Varieties of reading disability

Phonological and orthographic word decoding deficits and implications for interventions

Stefan Gustafson

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PREFACE

This thesis is based on the following five studies, which will be referred to in the text by Roman numerals.

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II. Samuelsson, S., Gustafson, S., & Rönnberg, J. (1996). The development of word-decoding skills in young readers. *Scandinavian Journal of Educational Research, 40,* 325-332.

III. Samuelsson, S., Gustafson, S., & Rönnberg, J. (1998). Visual and auditory priming in Swedish poor readers: A double dissociation. *Dyslexia, 4,* 16-29.

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CONTENTS

1. INTRODUCTION 1

2. DISABILITY RESEARCH AND READING DISABILITY 2
   2.1 Impairment, disability, and handicap 2
   2.2 The concept of normality 6
   2.3 Environmental demands on reading skills 8

3. MODELS OF READING 12
   3.1 The two components of reading 12
   3.2 A developmental model of word recognition 14
   3.3 Cognitive models of word recognition 16
   3.4 Memory and reading 20

4. READING DISABILITIES 23
   4.1 Developmental dyslexia 23
   4.2 Reading disabilities including comprehension deficits 28
   4.3 Surface and phonological types of reading disability 30

5. OBJECTIVES 31

6. SUMMARY OF THE STUDIES 32
   6.1 Study I 32
   6.2 Study II 34
   6.3 Study III 35
   6.4 Study IV 38
   6.5 Study V 40
   6.6 Summary of the findings 41

7. DISCUSSION 43
   7.1 General discussion 43
   7.2 Further research 48
   7.3 Conclusion 49

8. REFERENCES 50

1. INTRODUCTION

"And so to completely analyze what we do when we read would almost be the acme of a psychologist's achievements, for it would be to describe very many of the most intricate workings of the human mind, as well as to unravel the tangled story of the most remarkable specific performance that civilization has learned in all its history" (Huey, 1908/1968, p. 6).

Although written in the beginning of the last century, this sentence eloquently illustrates the challenge facing today's researchers examining reading and reading disabilities. Above all, it reminds us of the great complexity inherent in the process of reading. In order to be able to read and successfully comprehend even the simplest message, a large number of different sensory, perceptual, and cognitive operations have to be performed. The above quotation also highlights the fact that written language is a central aspect of society and that it is a cultural invention. Reading skills do not evolve spontaneously in human beings (cf. McGuinness, 1998), rather, reading is something that we must *learn* to do. Therefore, two basic societal requirements for the development of reading skills are that the surrounding society values these skills and that it supplies an adequate reading instruction.

Given the complexity of the process of reading, there are many different factors, internal as well as external to the individual, that can be assumed to influence the acquisition of reading. This also means that failure in learning to read can be the result of a complex interaction between different factors.

Though the examination of reading and its various components can be approached by studying the societal issues surrounding its acquisition, of specific interest to many researchers today are the internal mechanisms and processes that occur while a human is learning to read. Along these lines, many recent studies have attempted to isolate cognitive components associated with reading acquisition (e.g., Rack, Snowling, & Olson, 1992; Share & Stanovich, 1995; Wagner & Torgesen, 1987). Other studies have attempted to identify subgroups of reading disability based on cognitive skills directly related to the process of reading, that is, skill in using the two main word decoding strategies (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich, Siegel, & Gottardo, 1997).

The general aim of the present thesis is to analyse variations in the word decoding skills of reading disabled children and to relate these differences to possible cognitive, developmental, and, to some extent, environmental

causes of reading disabilities. Increased knowledge concerning varieties of reading disability could have implications for educational interventions for different groups of reading disabled children.

2. DISABILITY RESEARCH AND READING DISABILITY

It is difficult to provide a precise definition of disability research since it is not a homogeneous field of research. My own view is that disability research covers a variety of possible theoretical perspectives and methodological approaches. Researchers come into the field of disability research with very different disciplinary backgrounds and research interests. For example, a micro–macro distinction can be made where some disability researchers will focus mostly on the abilities and disabilities of the individual, while others will focus more on environmental factors.

I will begin this section by discussing the notions of impairment, disability, and handicap (these concepts are related to the micro-macro distinction just mentioned). I will then discuss the concept of normality, which is another central concept in disability research. These concepts will be exemplified by, and discussed in relation to, research on reading disabilities.

2.1 Impairment, disability, and handicap

The relationship between the individual and the environment is central to the classification system proposed by the International Classification of Impairments, Disabilities, and Handicaps, or ICIDH (World Health Organization, 1980). In this system, a disease is assumed to cause one or more impairments, where an impairment stands for "any loss or abnormality of psychological, physiological or anatomical structure or function" (WHO, 1980, p. 47). A disability is defined as "any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being" (WHO, 1980, p. 143). A handicap is defined as "a disadvantage for a given individual, resulting from an impairment or a disability, that limits or prevents the fulfilment of a role that is normal (depending on age, sex, and social and cultural factors) for that individual" (WHO, 1980, p. 143). Thus, in this classification system it is assumed that there is a cascading causation, where a disease causes impairment, impairment causes disability, and disability causes handicap.

The body affected by a disease is regarded as the starting point in this chain, whereas a handicap is described as a socialised situation:

"Handicap is characterised by a discordance between the individual's performance or status and the expectations of a particular group of which he is a member... Handicap is thus a social phenomenon, representing the social and environmental consequences for the individual stemming from the presence of impairments and disabilities" (WHO, 1980, p. 29).

In ICIDH it is acknowledged that sometimes the causal link between the concepts may not hold, and that in some cases there might even be a causal relation in the opposite direction: "The experience of certain handicaps can engender, as part of illness behaviour, not only various disabilities but at times even the impairment of certain faculties" (WHO, 1980, p. 30).

Nordenfelt (1983/1997, 1993) acknowledged that the classification system provided by the ICIDH (WHO, 1980) has some merits and has proven fruitful for the discussion of concepts related to disabilities, but he also identified some conceptual problems associated with this system. Nordenfelt (1983/1997) argued that there is an unclear distinction between the two concepts of disease and impairments since they are described in very similar ways. According to Nordenfelt (1983/1997), there is also an unclear distinction between the two concepts of disabilities and handicaps, since many descriptions of particular disabilities are in fact value-laden.

Other critics of the ICIDH (WHO, 1980) have focused mostly on the definition of handicap. The Canadian Society for the ICIDH and the Quebec Committees (1989, 1990) have specifically objected to the normative aspects of normality inherent in the definition of handicap in ICIDH (WHO, 1980). According to those critics, the *life habits* of a specific individual should determine when a handicap arises rather than the vague cultural norms of what a person should be able to accomplish in a particular society. Nordenfelt (1987, 1993) wanted to go one step further in the definition of handicap and not only include life habits, which can be described as repeated or repeatable actions, but also other actions which are important for a particular individual. Nordenfelt (1987) thus proposed that the *vital goals* of individuals should instead be focused on in the characterisation of handicaps and disabilities.

Some of the problems of ICIDH should be eliminated in a new classification, ICIDH-2, which is planned to be published in 2001 (WHO, 1999). According to a preliminary version of ICIDH-2, the new classification system will include three dimensions: (1) body level; (2) individual level; and (3) society level. These dimensions will be named Body functions and structure,

Activities, and Participation, respectively (WHO, 1999). In ICIDH-2, "functioning" will be used as an umbrella term covering positive or neutral aspects of the three dimensions whereas "disability" will be used as an umbrella term for problems in these dimensions (WHO, 1999). Note that ICIDH-2 is currently undergoing field trials and might be subject to changes. In the present thesis, the terms impairment, disability and handicap will be used in accordance with ICIDH (WHO, 1980).

An inclusive view of disability research would be that research conducted on any of the three levels of analysis: impairment, disability, and handicap, could be regarded as examples of disability research. However, even if a particular study only involves one level of analysis, disability research would probably benefit from acknowledging the existence of the other two levels. Reducing complex phenomena like disabilities and handicaps to only one level of explanation might lead to unnecessary theoretical paradoxes, as well as unnecessary misunderstandings between people representing different disciplines, professions, or ideological views (see Frith, 1999, and section 7 in this thesis). A continuos debate between different research paradigms and multi-disciplinary research environments may help to facilitate a broader awareness of both individual and societal aspects of disabilities and handicaps.

The need to consider both individual and environmental factors when studying disabilities can be illustrated by a reading disability example. An exclusive neurological or genetic explanation of reading disability would certainly fail to account for all factors involved, such as the obvious socio-cultural influences on reading skills or the fundamental importance of educational activities in learning to read. However, it does not follow that biological and genetic factors would have no influence on reading acquisition, as some researchers have argued (e.g., McGuinness, 1998). A child is not born as either a good or a poor reader but children can be expected to vary in their potential for acquiring reading skills, just like they vary in their potential for acquiring other skills (cf. Olson et al., 1989). Therefore, the possibilities of neurological deficits or genetic influences in reading disability are empirical questions and should be regarded as such (see section 4 for empirical findings). A complex phenomenon like reading disability should not be reduced only to its biological aspects, but neurological and genetic findings could provide valuable complements to findings on the behavioural and environmental levels of analysis (Frith, 1999).

Of course, a finding that supports one specific explanation or cause of reading disability, by stressing a particular individual or environmental

factor, does not rule out other explanations of reading failure and should not be over-generalised to the whole population of poor readers. Thus, even if a genetic component is found in developmental dyslexia, it does not imply that there is a genetic component in all forms of reading disability. Within a group of reading disabled individuals there seem to exist substantial individual differences regarding the relative influence of genetic compared to environmental factors (Castles, Datta, Gayan, & Olson, 1999; Wadsworth, Olson, Pennington, & DeFries, 2000).

It should also be noted that neurological impairments are by no means fixed or resistant to treatment. Recent findings in the neurosciences provide evidence of brain plasticity not only in children, but also in adults who have suffered damage to the brain as a consequence of tumours (Seitz et al., 1995), or stroke (Chollet et al., 1991; Johansson, 2000). Findings also suggest that a stimulating environment may be critical for the outcome of interventions aimed at overcoming disabilities caused by acquired as well as congenital neurological impairments (Johansson, 2000; Mattsson, Sørensen, Zimmer, & Johansson, 1997; Schrott et al., 1992). Furthermore, even if a particular neurological impairment would be impossible to treat at a given time, the actions and opinions of the surrounding environment, such as political decisions and social and technological developments, would continue to affect the individual, directly or indirectly.

In the present thesis, the terms "reading disability" and "reading disabled children" will be frequently used. How then, are these concepts related to the concepts of disability and handicap? I would suggest that as soon as a reading disabled individual encounters demands on reading skills which exceed his or her current reading ability, the individual is handicapped in that particular situation. In the empirical studies of this thesis, the demands on reading skills are very pronounced, since a number of timed tests measuring word decoding skills and reading comprehension were administered. In a test situation, the possibility of using environmental compensatory strategies, such as asking for help or using technical aids, which could sometimes be used in real life situations, is also typically minimised. In other words, the focus of a test is on the reading disability and not on the handicap associated with this disability. The focus on internal abilities and the exclusion of many environmental factors influencing the lives of reading disabled children is a limitation of the present thesis (even though study IV included measures of print exposure). However, a general aim of these empirical studies is to learn more about different groups of reading disabled children in order to facilitate more adequate educational interven-

tions. Also, even if disability research is focused on one level of analysis, this need not be a problem as long as the results are interpreted and discussed in light of the other levels. What seems important is that the results from one level of analysis are not over-generalised to the other levels. Instead, some understanding of other levels could help generate new hypotheses or cross-validate specific interpretations of empirical findings (cf. Frith, 1999).

2.2 The concept of normality

Disability research includes a wide variety of possible theoretical frameworks and methodological approaches. However, there are some common themes and concepts which often need to be addressed, explicitly or implicitly. For example, the interaction between the individual and the environment seems to be one such common theme in disability research. Another theme that will often enter the research process is the classification and definition of different disabilities. This can be exemplified by study I in the present thesis which critically examined the inclusion of IQ in the definition of developmental dyslexia. Additionally, the process of diagnosis and the effects of receiving a diagnosis are other related themes. For a comprehensive study of how children, parents, and teachers talk about and give meaning to the diagnosis of dyslexia, see a recent thesis by Zetterqvist Nelson (2000).

In this section, I will focus on another concept, normality, which seems to be one of the central concepts in disability research and also has a direct bearing on research and current debates in the field of reading disabilities. The concept of normality was introduced in western society by statisticians as late as in the 19th century (Davis, 1997). The statistical notion of normality relies on the assumption of the normal distribution of abilities, also known as the bell-shaped curve, with the majority of cases being positioned in the middle, or "normal", part of the distribution. This notion incorporates some paradoxes, which can be illustrated by research on reading disabilities. One such paradox is that since the bell-shaped curve is taken for granted in statistical analyses, then "norming the non-normal is an activity as problematic as untying the Gordian knot" (Davis, 1997, p. 14). If there is always a bell-shaped curve, it follows that there will always be some individuals situated at the lower end of the continuum, regardless of the general level of performance. Thus, a reader positioned at the lower end of the continuum in a society with a high general reading ability may be regarded as a normal reader in another society with a low general level of

reading ability. Furthermore, even if the general level of reading ability improves in a population, there will still be just as many statistically subnormal readers within that population.

This can be illustrated by a comparative study of reading literacy organised by The International Association for The Evaluation of Educational Achievement (IEA) (see Taube, 1995). Taking place in 1990/1991, this study used different measures to evaluate the reading skills of 9-year-old and 14-year-old children from 31 different countries. The results showed that when a composite measure of text reading ability was formed, Sweden ranked third highest among all countries both for the 9-year-olds and the 14-year-olds. The mean score of the top-ranked nation, Finland, was 569 for 9-year-olds, compared to the lowest mean score of 383 for Venezuela. Interestingly, differences also occurred between countries with similar economic resources and in the same geographic area. For example, the mean score of the Swedish 9-year-olds (539) were higher than that of the Danish 9-year-olds (475). In fact, the 25th percentile (i.e., 25% performed below this score) of the Swedish pupils was higher than the mean score of the Danish pupils (Taube, 1995). Thus, if a single bell-shaped curve, including both Swedish and Danish children, would be formed, more Danish than Swedish children would be found in the lower tail of the normal distribution. If separate distributions would instead be used, a Swedish pupil, located at the 5th percentile, for instance, would be expected to perform at a higher level than a Danish pupil also located at the 5th percentile.

Besides the statistical notion of normality, the concept can have a normative meaning. Now, what is considered normal is not based on statistical comparisons but on cultural and societal norms and values. As long as there are only quantitative and no identifiable qualitative differences between reading disabled individuals and "normal readers", the cut-off point between subnormal and normal will always be arbitrary to some extent. This means that the societal norms will affect what proportion of children will be categorised as reading disabled. Higher requirements would be associated with larger proportions of reading disability if the general level of reading ability is held constant. However, the general level of reading ability would also be affected by societal norms and values, for example, through the allocation of educational resources. How much resources are available for interventions might also affect what proportion of children will be categorised as reading disabled, because the identification of a "subnormal" group, like reading disabled children, may be associated with certain responsibilities for decision makers. There might be a resistance to

acknowledge that a large percentage of children are in need of extra resources if no such resources are judged to be available. Thus, according to Aaron (1997), the number of children who are identified as reading disabled may sometimes be the result of fiscal, rather than psychological, decisions. This also means that the number of children categorised as reading disabled may vary from year to year, depending on how much resources are allocated to a particular school district (Aaron, 1997).

No radical solution to these dilemmas will be provided in this thesis. The normal distribution will enter the statistical analyses as usual, and the term "normal readers" will also be used occasionally, with reference to the control groups included in the empirical studies. It seems difficult to completely avoid the concept of normality while conducting disability research. For example, disabled people who participate in disability research often do so because they differ from a given norm in some respect. However, while including these notions and statistical measures of normality, I fully acknowledge the difficulty and complexity of using them. In conclusion, what is considered normal and abnormal depends on both individual and environmental factors and what is considered abnormal in one particular society would be considered perfectly normal in other societies.

2.3 Environmental demands on reading skills

Given that a handicap arises partly as a result of environmental demands and that these demands can be expected to change over time, the current demands on reading skills in Sweden need to be discussed. The level of reading skills and the demands on these skills will interact to create the measurable qualification of a reading handicap. A related question, which will also be discussed in this section, concerns the secondary effects of reading disability, that is, what are the personal and social consequences of failing to acquire the level of reading skills required by society? A third question considers the implications of the rapidly developing information and communication technology for reading disabled individuals. This technology may further increase the societal demands on reading skills but should also offer new opportunities for compensation for reading disabled people. Although each of these questions could produce their own thesis, in the present work they will only be discussed briefly as background to the empirical studies, with the environmental demands being more or less taken for granted.

In school, reading is clearly one of the most fundamental activities. It is easy to overlook how much educational time and effort is usually spent on teaching children how to read and write and to continuously improve on these skills. Reading skills are fundamental in all theoretical subjects in school, since written language is a critical source of information and communication. Even when information is provided orally in school, written language in the form of note-taking is often used to preserve a more robust representation of what is said than the information that will be stored in memory upon hearing it. This illustrates one of the most remarkable benefits of written language compared to spoken language. Written language is more decontextualised, since it is not dependent on events occurring at certain places and times:

"A technology which allows the user to communicate with others from whom he/she is removed in space and time is certainly miraculous and has indeed had the most profound consequences for the living conditions of mankind. No wonder that mastery of such a remarkable system as written language has become a highly valued skill and prerequisite for success in our society" (Lundberg & Høien, 1997, p. 11).

The intense reading instruction that children receive in school reflects the high demands on reading skills of today's society. There are countless activities which include written language in some form. The nature of these activities and the motives behind participating in them vary considerably. For example, written language can be used as a source of information, as a tool for communication with others, as our "externalised memory", as a means of personal expression, as part of our work, as a social act when we read together with, or for, someone else, and it can be used for recreational purposes. These activities also vary in terms of the required levels of word decoding and comprehension skills (see section 3.1) and the possibilities of using compensatory strategies, such as asking for help or using technical aids. However, all of these different activities require that we have basic skills in reading and writing.

Purves (1990) emphasises that environmental demands on reading skills are not restricted only to the technical aspects of transforming strings of letters into words. The importance of cultural literacy is discussed in terms of membership or non-membership in a "scribal society" in which a number of assumptions about the world is shared. Purves (1990) here makes a distinction between the literate, who merely possesses basic skills in reading and writing, and the "scribe" who is a master of written language and not only knows how to read and write but also knows most of the specific

conventions of written language, as well as a body of texts which are valued by a particular scribal society. According to Purves (1990), scribes tend to manage society because they have control of the information and its flow. In the context of the rapidly developing information technology in the United States, he notes that: "the distinction between the literate and the scribe has come to take on increasing social and even economic weight, and it looks as if the gap will only widen" (Purves, 1990, p. 38).

Even though this analysis was based on the situation in the United States, the general idea that cultural literacy is critical for success in many areas of society and that written language can be used to exclude groups of people from being full members of various scribal cultures may apply to most literate societies, including Sweden. In many cases, to be a normal reader, or merely literate, might simply not be enough. In order to be a successful member of a particular field of society, the individual must also meet a number of demands which have to do with knowledge of the conventions and important texts of that scribal society (Purves, 1990). Thus, a distinction between normal readers and people with reading disabilities is a simplified way of categorising people according to level of reading skills. However, the importance of social and cultural aspects of written language does not lessen the importance of the more technical aspects of reading. It is possible that the technical skills are necessary but not sufficient requirements in reaching high levels of cultural literacy.

Since reading skills are of fundamental importance in our society, failure to acquire these skills might have negative secondary effects for the individual. A number of studies have examined the possible links between reading disability and various types of behavioural problems. In a study by Adams, Snowling, Hennessy, and Kind (1999), prosocial behaviour was positively correlated with reading ability, whereas conduct problems were negatively correlated. A modest, but statistically significant 4% of the variance in concurrent reading was accounted for by teachers' ratings of children's behaviour. In another study, the relationship between reading problems and antisocial behaviour was examined (Maughan et al., 1996). The results suggested that juvenile offending was most strongly predicted by poor school attendance. Reading problems only seemed to be indirectly related to risk for offending, via the poor readers' poor school attendance. This result is in line with a recent Swedish study concerned with the prevalence of reading disabilities among prison inmates (Samuelsson, Gustavsson, Herkner, & Lundberg, in press). The results of this study suggested that, in general, the observed reading difficulties among prison

inmates could be explained by their poor social and educational backgrounds, rather than being caused by specific reading disabilities of constitutional origin (i.e., developmental dyslexia, see section 4.1).

In correlational studies like these, however, it is not really possible to determine the causal direction of the relationship. Problems of behaviour might be a secondary effect of reading disability but there might also be a causal link in the other direction, that is, problems of behaviour might lead to reading difficulties. The exact nature of this relationship and its causal direction does not seem to be clear at this point. It also seems that knowledge is largely lacking concerning many other possible secondary effects of reading disability, such as the educational and vocational situations of people with reading disabilities living in Sweden.

General environmental developments may sometimes have profound effects on specific disabilities and handicaps. For example, the rapidly developing information and communication technology should offer new possibilities for compensation for people with reading disabilities. Tools such as scanners, speech synthesis, and speech–to–text conversion may facilitate better access to text-based information and provide new bridges between spoken and written language. Information and communication technology also offers new possibilities of using computers for educational purposes, through various types of programs for reading instruction. On the other hand, as long as the information and communication is mainly based on written language and there is limited opportunity of using compensatory technological tools, this technology also imposes new demands on reading and spelling skills, and thus, might accentuate some of the negative aspects of being reading disabled. Access to information and communication channels seems to be one of today's most central democratic issues, and this issue could be even more critical for people with reading disabilities who are in a vulnerable position because of their difficulties in using written language (cf. Purves, 1990).

Reading and reading disabilities are complex phenomena which can be analysed on several different levels of analysis; but even if the analysis is restricted to the cognitive level, they are not clear-cut concepts. Different reading activities can be expected to vary in terms of their specific cognitive requirements. Some activities may require a very rapid and automatic transformation of letters into words, while other reading tasks may put higher demands on higher–level mental processes. The complexity of transforming strings of abstract symbols (i.e., letters) into meaningful entities (i.e., morphemes, words, and sentences) also implies that there are

several possible cognitive causes of reading failure. Thus, before going any further the cognitive process of reading needs to be examined in some detail.

3. MODELS OF READING

3.1 The two components of reading

The process of reading can be divided into two components: word recognition and comprehension (Aaron, 1997; Gough & Tunmer, 1986; Hoover & Gough, 1990). Word recognition (or word decoding) refers to the technical aspect of reading, that is, to transform written words into their corresponding sounds. However, the general purpose of reading is to gain meaning in what is written and this is the role of the second component, comprehension (or understanding). The process of understanding is an activity on a higher cognitive level where the reader makes use of personal experience, interpretations are made, and conclusions are drawn. This mental activity is similar to the mental activity engaged in listening to a text read by someone else (Aaron, 1997).

There is empirical support that these two components are to some extent independent of each other, such that one of the components can be selectively impaired while the other is more or less intact (Oakhill, 1982; Share & Stanovich, 1995; Stothard & Hulme, 1992). An example of impaired word recognition skills but intact comprehension would be developmental dyslexia (cf. Share & Stanovich, 1995). An extreme example of the opposite pattern, intact word recognition skills but impaired comprehension, would be the case of hyperlexia (Aaron, Franz, & Manges, 1990; Healy, 1982). However, there are also crucial dependencies between the two components. In order to be able to understand what is written, the words always have to be decoded. Thus, in a timed test of reading comprehension dyslexics would be expected to perform below normal even if their comprehension is intact. If the word decoding process in itself requires much effort, there should be less processing capacity left for accessing the meaning of what is written, thus, a deficit in comprehension.

There might also be more long-term secondary effects of impaired word decoding skills on higher–level, semantic abilities. Stanovich (1986) described such "Matthew effects" in reading (from the Gospel according to St Matthew, 25:29) and explained how a low initial level of word decoding skill in children may have long-term negative effects on their verbal IQ. One reason for such negative effects is that word decoding difficulties may

negatively affect the motivation to read. If reading disabled children tend to avoid written language, there would be an increasing gap in reading ability between them and children without any reading difficulties. The vocabulary of reading disabled children would also be expected to grow at a slower rate due to their relatively limited exposure to written language. Thus, even if a child initially has a specific deficit in word decoding, there might be secondary snowballing effects of this specific deficit leading to more general difficulties (Høien & Lundberg, 1992; Stanovich, 1986). This should not be understood in a deterministic sense. Instead, it should be regarded as another reminder of the importance of early and appropriate interventions.

Although the two components, word recognition and comprehension, are related to each other, Aaron (1997) proposed that they can be used as a basis for categorising poor readers into three subgroups: specific reading disability or developmental dyslexia (associated with deficient word recognition but adequate comprehension), nonspecific reading disability (associated with poor comprehension but adequate word recognition), and generalized reading disability (associated with difficulties in both comprehension and word recognition). Aaron (1997) argues that this categorisation system is more outcome-based than traditional definitions of reading disability, due to the fact that the three subgroups suggest different remedial instructions.

Even if the purpose of reading is to understand what is written, there is strong evidence that the development of word recognition skills is the most foundational task in early reading acquisition (cf. Share & Stanovich, 1995). Difficulties in word decoding also seem to be the main problem for most at-risk and reading disabled children (Bruck, 1988; Perfetti, 1985; Share & Stanovich, 1995; Stanovich, 1986; Vellutino & Scanlon, 1987). As the general level of reading ability increases, the proportion of variance accounted for by word recognition decreases and the proportion accounted for by comprehension increases (Curtis, 1980; Daneman & Carpenter, 1980; Stanovich, Cunningham, & Feeman, 1984), however, word recognition continues to account for a substantial amount of variance in reading ability in adults as well (Cunningham, Stanovich, & Wilson, 1990; Liberman, Rubin, Duques, & Carlisle, 1985; Perfetti, 1985). Because of the importance of word recognition in early reading acquisition and in explaining reading difficulties in reading disabled children, this component will be focused in the present thesis, even though the empirical studies also included measures of the comprehension component.

3.2 A developmental model of word recognition

In the previous section it was stated that word recognition skills are fundamental in early reading acquisition. This is partly due to the fact that there are several ways of recognising words and that novice readers are not able to use the same word decoding strategies as skilled readers. Høien and Lundberg (1988) presented a stage model of the development of word recognition skills with the following sequence of stages: pseudo-reading, logographic–visual, alphabetic–phonemic, and orthographic–morphemic reading (see Figure 1).

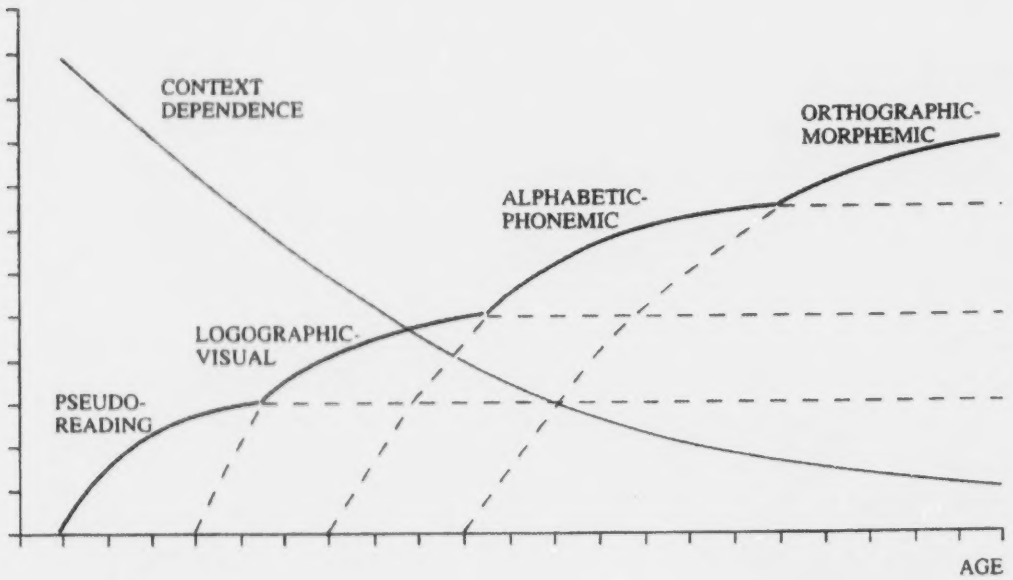

Figure 1. Stages of decoding development. As the child advances in development the dependence on context is decreased as indicated. Dotted lines indicate that a given strategy is still available although no longer dominating (Høien & Lundberg, 1988).

In the pseudo-reading stage of this model, the child relies on contextual cues to read without paying much attention to print itself. For example, the child may guess that the word "milk" is printed on a milk carton but would typically give the same response even if a different word was written on it. In the next stage, the logographic–visual, printed words are processed as mere visual patterns. The alphabetic principle has not yet been mastered here and the child learns to read new words by increasing his or her "sight vocabulary". There is still a high reliance on contextual cues in this stage. As the number of words in the "sight vocabulary" increases, the load on

memory also increases, and a new strategy is eventually required to make progress in word decoding.

The transition to the alphabetic–phonemic stage requires that the child starts paying attention to the individual letters of words and their corresponding sounds. Thus, the task now is to break the alphabetic code. When children have learned to map graphemes with their corresponding phonemes, they are much less dependent on contextual cues because they will then be able to sound out words never seen before as well as words presented out of context. The alphabetic–phonemic strategy is more efficient than the strategies of previous stages because it utilises the basic principle of our writing system. However, since it requires that individual graphemes are converted into phonemes, it is a slow and rather strenuous process (Høien & Lundberg, 1988).

In the final stage, orthographic–morphemic decoding, the reader is able to process multi-letter units as unified patterns in his or her mental lexicon. At this point, word decoding has become instant, automatic, and no longer depends on grapheme–phoneme conversion. Høien and Lundberg (1988) stress that the orthographic–morphemic stage should not be confused with the more primitive visual–logographic stage. In orthographic–morphemic word decoding, all letters and letter positions are of critical importance, but they are organised in higher-order structures. According to Høien and Lundberg (1988), orthographic–morphemic processing builds upon sub-lexical information, and therefore it is misleading to use terms such as "whole-word reading" or "Chinese reading" for this type of reading. Chinese reading is also an inappropriate term because Chinese signs provide phonological as well as semantic information (McGuinness, 1998).

Children are assumed to pass through these stages of reading development in the same order, and a change from one stage to another is brought about by increasing task requirements (Høien & Lundberg, 1988). In the developmental model, a stage is regarded as the dominating strategy during a specific stage of development, although it builds on previous stages which are still available as back-up functions when the new strategy cannot be used (hence the dotted lines in Figure 1). For example, skilled readers using the orthographic–morphemic strategy might still use the alphabetic–phonemic strategy when reading unfamiliar words.

There are other stage models which propose the occurrence of similar changes in word decoding strategies during reading development. Thus, it is generally assumed that there is a gradual shift from more reliance on phonological word decoding to reliance on orthographic decoding in the

later stages of reading acquisition (Ehri, 1987; Ehri & Wilce, 1987; Frith, 1985; Juel, Griffith, & Gough, 1986). It is also suggested that poor readers rely on phonological information for word identification to a greater extent than do normal readers of the same age. Although an orthographic reliance is found in skilled young readers, their phonological skills continue to develop throughout childhood (Backman, Bruck, Herbert, & Seidenberg, 1984), suggesting that there is no clear dissociation between these word decoding skills (Aaron, Wleklinski, & Wills, 1993; Juel et al., 1986).

Thus, the stage models and findings concerning the relation between word decoding skills suggest that poor phonological word decoding would normally exclude skill in orthographic word decoding. Furthermore, skilled orthographic word decoding would frequently include skill in phonological decoding. A reading disabled child, suffering from phonological deficits, would experience difficulties in acquiring both phonological and orthographic word decoding skills (Stanovich, 1988a; Stanovich & Siegel, 1994). Considerable progress in reading might be made by relying on visual strategies and other intact mechanisms, with some reading disabled children learning to read by gradually increasing their "sight vocabulary" of printed words (Snowling & Hulme, 1989). However, this would correspond more to logographic than to skilled orthographic decoding. By learning to read in this way, the lexical system of the child would lack the complex set of connections between letters and sounds which characterises the lexicon of a reader in the orthographic stage of reading development (Høien & Lundberg, 1988; Seymour, 1986).

Bearing these general models in mind, it is important to not ignore individual differences in the development of word decoding skills (cf. Share & Stanovich, 1995). Some of these differences might be due to developmental aspects of word recognition, but it is also possible that differences in word decoding reflect different underlying cognitive deficits or differences stemming from environmental factors such as type of reading instruction or amount of print exposure (Manis et al., 1996; Stanovich et al., 1997; see also study III and IV of the present thesis).

3.3 Cognitive models of word recognition

Stage models of reading acquisition are related to dual-route models of word recognition. Ellis and Young (1988) have presented such a dual-route model, which describes two routes from print to meaning (see Figure 2).

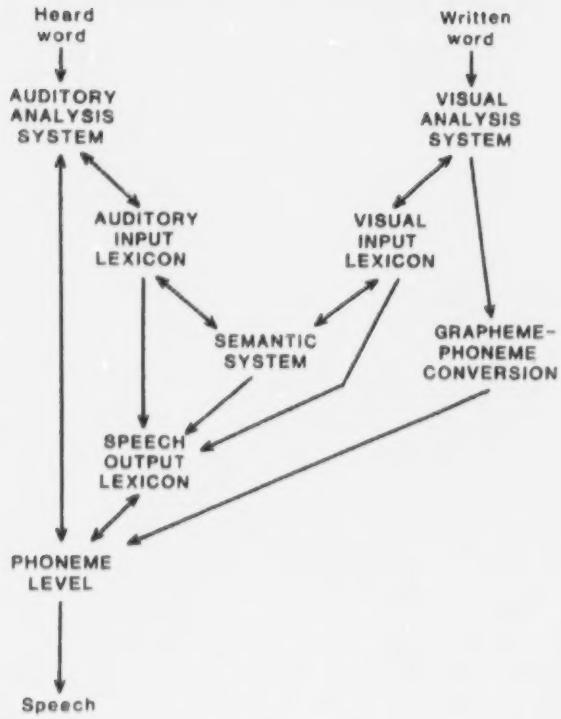

Figure 2. Functional model for the recognition, comprehension and naming of written words in reading (Ellis & Young, 1988).

The top left of this model deals with the recognition of spoken words. In this process, the auditory analysis system transforms the sound into a form that is recognisable by the auditory input lexicon. This lexicon contains representations of all words familiar in their spoken form. The meanings of words are contained in the semantic system and a heard word is not understood until it has triggered the activation of that word's semantic representation.

For written words there are two different routes to the semantic system. First, the visual analysis system identifies the letters of a word and notes each letter's position (this is assumed to be a strictly visual process). Words that are familiar in their written form are represented in the visual input lexicon, and skilled readers who have learned to recognise thousands of words have a representation for each of these words. When reading a familiar word, the representation of that word in the lexicon is activated, and the semantic representation of that word has to be activated in order to understand its meaning (Ellis & Young, 1988).

However, in order to be able to read unfamiliar words (i.e., words not represented in the visual input lexicon), the reader has to use an alternative

strategy. This alternate process also starts with the identification of the letters of words and their positions in the visual analysis system. The letters (graphemes) are then converted to sounds (phonemes). The output of this grapheme–phoneme conversion is an activation of phonemes at the phoneme level. Now the words can be articulated, either by speaking them out loud or by using inner speech. The words have now been converted to their auditory form and can be analysed in the auditory analysis system, as if the words had been heard. If the words are familiar in their spoken form, the representations in the auditory input lexicon are activated. Finally, the meaning of the word can be accessed by activating representations in the semantic system. Thus, by using this alternative route, words that are visually unfamiliar still can be understood if the reader has heard the word before and knows its meaning. Young or unskilled readers, not having many visual representations of words in their visual input lexicon, often rely on this process (Ellis & Young, 1988).

Reading disabled children would encounter difficulties following both the first and the second route of this model. If reading is a difficult task for the child and progress is slow, the visual input lexicon will expand at a slower rate than for normal readers. Furthermore, if the child has underlying phonological deficits (see section 4.1 of this thesis), he or she would experience difficulties in using the alternative, phonologically based route. Phonological deficits might impair grapheme–phoneme conversion as well as processing in the auditory analysis system.

Some comments should also be made concerning this model's relation to other theoretical concepts. In this model, the first route, from the visual analysis system to the visual input lexicon, is similar to both the visual–logographic and the orthographic–morphemic word decoding strategy suggested by Høien & Lundberg (1988). However, as pointed out by Høien and Lundberg (1988), orthographic–morphemic word decoding should not be confused with the more primitive visual–logographic strategy and it seems that in the model of Ellis and Young (1988), this distinction is not made. When using the concept of orthographic decoding in the present thesis, I refer to an advanced and automatic word decoding strategy; that is, one which builds on sublexical information. In this strategy all letters and letter positions are processed, but they are also organised into higher-order structures. Thus, the words still have to be decoded and orthographic decoding is only a "direct" route from print to meaning in the sense that it does not require that individual graphemes are converted into phonemes (Høien & Lundberg, 1988; Liberman, 1999; see also Ehri, 1992).

The second route, from the visual analysis system, via grapheme–phoneme conversion, to the auditory input lexicon, seems to be identical to the alphabetic–phonemic strategy described by Høien & Lundberg (1988). In the present thesis, this word decoding strategy will most often be referred to as phonological word decoding. Although this word decoding strategy is sometimes labelled the "indirect" route, there is evidence that phonological decoding can sometimes be very quick, perhaps even faster than the visual–orthographic route (Liberman, 1999; Lukatela & Turvey, 1994a; 1994b; Perfetti & Bell, 1991).

However, other models of visual word recognition have raised questions as to the necessity of a dual-route system. In the alternative, single-route models of reading, it is instead assumed that "there is a single, uniform procedure for computing a phonological representation from an orthographic representation" (Seidenberg & McClelland, 1989, p. 525). According to Seidenberg and McClelland (1989), written language (i.e., written English) is a quasiregular system; that is, a body of knowledge that is systematic, but still admits irregularities. It is argued that as a consequence of its quasi-regular nature, knowledge of written language can be best represented by "weights on connections between simple processing units in a distributed memory network" (Seidenberg & McClelland, 1989, p. 525). In such a connectionist network, learning is conceptualised as modifying the weights on the connections between linguistic units by exposure to written language. Note that there is no need for any explicit rules in such a model of reading acquisition. Computer programs designed to simulate connectionist models of word recognition display implicit learning from the correspondences between letters and sounds in the sets of words that are presented to them. According to Seidenberg and McClelland (1989), their model was able to account for behavioural data that dual-route models had failed to explain. Seidenberg and McClelland (1989) thus argued that it was able to account for differences among words in terms of processing difficulty, differences in reading skill, and findings about reading acquisition. However, proponents of a dual-route model did not agree with that conclusion and instead argued that dual-route models could better account for all these findings (Coltheart, Curtis, Atkins, & Haller, 1993).

The purpose of this thesis is not to examine the relative strengths and weaknesses of dual-route and single-route models, therefore, I will not elaborate on the details here. Overall, it seems that both dual-route and single-route models have their specific merits and limitations. There have also been several attempts to modify both types of models to better account

for the empirical findings (Coltheart et al. 1993; Hulme, Snowling, & Quinlan, 1991; Luo, 1996; Taft, 1991), and a combined model has also been proposed (Bjaalid, Høien, & Lundberg, 1997).

The empirical studies of the present thesis are rooted in dual-route theory. Therefore, in these studies it is generally assumed that there are two main word decoding strategies, a visual–orthographic and a phonological strategy. However, this should not be regarded as a theoretical statement against single-route models. Instead, single-route models can be regarded as alternative frameworks for interpreting the results.

3.4 Memory and reading

Memory is central in most cognitive processes and this also applies to the process of reading. The associations between memory and reading have been extensively studied (Baddeley, 1978; Brady, 1991; Gathercole, Willis, & Baddeley, 1991; Wagner & Torgesen, 1987). These studies have mainly focused on short term memory, or working memory, in relation to reading. The results generally show that reading disabled individuals perform below normal on measures of verbal short term memory, or working memory, which is in line with the hypothesis that reading disability is associated with phonological deficits (Baddeley, 1978; Estes, 1973; Wagner & Torgesen, 1987).

However, short term memory is not the only type of memory related to the process of reading. In the field of memory research there has recently been a great interest in findings concerning two different functions of the long-term memory store, referred to as implicit and explicit memory. Research has demonstrated a variety of striking dissociations between implicit and explicit memory, and that these two types of memory can be independent of one another (Cohen & Squire, 1980; Graf, Squire, & Mandler, 1984; Jacoby & Dallas, 1981; Warrington & Weiskrantz, 1968; 1970). According to Graf and Schacter (1985, p. 501): "Implicit memory is revealed when performance on a task is facilitated in the absence of conscious recollection; explicit memory is revealed when performance on a task requires conscious recollection of previous experiences". Thus, implicit memory seems to be synonymous with unconscious memory, whereas explicit memory consists of conscious recollections.

The terms explicit and implicit memory also correspond to the use of two different types of tests. Explicit memory is revealed by traditional memory tests of recall or recognition in which subjects try to recall or recognise stimuli from a previous study. In implicit memory tests, the unconscious

influence of stimuli presented at study on performance at test is measured. The measure of interest in most implicit memory tests is priming effects. Priming occurs "when exposure to words, pictures, or other items facilitates subsequent processing of those items on tasks that do not make explicit reference to the prior study episode" (Schacter et al., 1990, p. 1079). In a test of implicit memory, it is of fundamental importance that the subjects are not using explicit memory strategies to solve the task; that is, they should not consciously recollect stimuli from the study phase. To achieve this objective, it is necessary to use reduced cues in some form. For example, the words used at study can be modified at test by removing the ending letters of the words so that only the first two or three letters of each word remain as cues (i.e., "ele___" for the target word "elephant"). The participants are then instructed to complete the word stems with the first word that comes to mind. The amount of priming can then be measured by observing how many of the words presented at study are later generated at test and comparing this number with a baseline; that is, the number of target words being generated from the word stems without any previous study of them. The difference between the study-test procedure for stem completion and baseline completion then constitutes the magnitude of priming. Word stem completion tests were used in study III and IV of the present thesis as measures of visual implicit memory.

A number of studies have demonstrated dissociations between implicit and explicit memory across a wide variety of tasks and conditions. Studies of amnesic patients generally show that, although they perform very poorly on explicit tests of memory, they perform remarkably well, and frequently at normal, on measures of implicit memory (Cohen & Squire, 1980; Graf et al., 1984; Warrington & Weiskrantz, 1968; 1970). Dissociations between explicit and implicit memory have also been observed in normal subjects (Jacoby, 1983; Jacoby & Dallas, 1981; Weldon & Roediger, 1987).

According to the multiple memory systems view (Squire & Cohen, 1984; Tulving & Schacter, 1990), the observed differences between implicit and explicit memory can be ascribed to different properties of hypothesised underlying separate memory systems. For example, Squire and Cohen (1984) argued that explicit recollection is a property of, and supported by, a declarative memory system which is involved in verbalisable knowledge such as the formation of new representations or data structures. Implicit memory, in turn, is attributed to a procedural system which is involved in skilled behaviour with no need for conscious recollection. It is assumed that different neural structures underlie performance on different tests tapping

the two kinds of memory and dissociations between implicit and explicit memory are explained by appealing to the different systems. Because these systems are thought to be largely independent, dissociations are to be expected.

Another multiple memory systems theory is the perceptual representation system (PRS) account (Schacter, Cooper, & Delaney, 1990; Tulving & Schacter, 1990). According to the PRS account, explicit memory tests are assumed to tap the episodic memory system. Perceptual priming, on the other hand, reflects operations of visual and auditory perceptual representation systems; that is, cortical regions that represent the form and structure of stimuli but not the semantic meaning and associating properties of words and objects. Thus, implicit memory is assumed to be presemantic and priming effects would be based solely on perceptual characteristics of the stimuli, not on semantic elaboration. Conceptually driven processes such as elaborating, organising, and reconstructing are assumed to belong to a third system: the semantic memory system. The great majority of studies of implicit memory have used tests involving visual processing, however, in a series of experiments Schacter and Church (1992) used two auditory implicit memory tests. The results were consistent with the hypothesis that a presemantic auditory perceptual representation system played an important role in observed auditory priming.

The hypothesised visual and auditory perceptual representation systems seem to correspond well to the visual and auditory input lexicons proposed in the dual-route model by Ellis and Young (1988). In study III and IV of this thesis, the possible interaction between the use of the two main word decoding strategies and the magnitude of visual and auditory priming, presumably tapping the perceptual representation systems, was examined. If the auditory and visual PRS are both impaired in reading disabled children, then these children should show less perceptual priming than normal readers for both auditory and visual information. Their relative performance would depend on which PRS, the visual or auditory, was most severely impaired. It should also be noted that, as shown in Fig. 1, there are links from the auditory and visual input lexicons to the semantic system. This suggests that even if the semantic system is functioning normally, an impaired input lexicon might lower the performance on a semantic test.

4. READING DISABILITIES

In recent years, the concept of developmental dyslexia has gained status in Sweden as well as in many other countries (Solvang, 1998). This motivates a thorough review of theories and empirical findings concerning developmental dyslexia. However, not all reading disabled children fit a traditional definition of dyslexia, which will be discussed in section 4.2. In this section, I will also critically discuss the assumption of specificity in developmental dyslexia and point to the problems of including overall intelligence in the classification of reading disabilities. Finally, in section 4.3, I will present an alternative classification, which is based on relative strengths in orthographic and phonological word decoding.

4.1 Developmental dyslexia

One basic distinction should first be made between developmental and acquired dyslexia. Developmental dyslexia refers to the problem of creating a new function (literacy) which has failed to develop normally. On the other hand, in acquired dyslexia the cognitive function has been impaired or lost as a consequence of neurological damage (Seymour & Bunce, 1994).

More than 100 years have passed since Pringle Morgan (1896) described a case of "congenital word-blindness". Since then, researchers have gained some knowledge about the causes and manifestations of congenital reading difficulties, which are now often referred to as developmental dyslexia. However, many questions still remain in this field of research. In fact, there is still no general agreement on the exact meaning of the concept of developmental dyslexia. The word dyslexia is put together by the two Greek words *dys* and *lexia*, which is translated as "difficulties with words". The term dyslexia has generally become accepted within the scientific community. Other synonymous terms are "word-blindness" and "specific reading disability". The term word-blindness is misleading because it suggests that dyslexia is primarily constituted by a deficit in vision, which is not the case (Aasved, 1989; Goldberg & Schiffman, 1972). It could also be too pessimistic because, even if dyslexics have reading difficulties, it is still possible for them to read and their reading skills could also be improved by means of adequate reading instruction. The term specific reading disability is somewhat impractical, simply because of its length.

There has been some debate as to the existence of any qualitative differences between dyslexics and poor readers in general, or if dyslexics are

simply at the end of a continuum of individuals representing different levels of reading skill (e.g., Bryant & Bradley, 1985). The basic distinction between dyslexics and poor readers is sometimes based on neurobiology. Thus, according to Vellutino (1978), dyslexia is a medical term, referring to a reading disorder that is due to some form of neurological dysfunction rather than to environmental factors. This statement is in line with the definition of dyslexia suggested by World Federation of Neurology in 1968:

"a disorder manifested by difficulty learning to read, despite conventional instruction, adequate intelligence and socio-cultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin" (Critchley, 1970, p. 11).

This definition does not tell much about what dyslexia really is, however. Rather, it is dominated by excluding criteria. In spite of strong efforts, there is still no general agreement on a single, more operational definition of the term which would contain specific information of the etiology of dyslexia. Some controversies concerning the definition could stem from different levels of explanations in different theoretical accounts (Frith, 1999; Miles, 1995, see also section 7).

According to early accounts of dyslexia, it was constituted by low-level visual perceptual deficits (Bender, 1956; Birch, 1962; Orton, 1925; 1937). During this period, it was believed that dyslexia was caused by problems in visual organisation and visual memory. The types of reading errors which are frequently observed in dyslexia (i.e., reading *b* as *d*, as well as orientation and sequencing errors) were taken as evidence in support of visual perceptual deficits. However, such errors do not mean that dyslexics see or perceive the letters and words differently from other readers. Rather, it could instead be attributed to general difficulties in verbal processing; that is, in associating verbal labels with printed symbols (Vellutino, 1978).

Today, there is evidence that dyslexia is not primarily caused by deficits in vision (Aasved, 1987, 1989; Goldberg & Schiffman, 1972; Goulandris et al., 1998), and other studies also suggest that visual perception and visual memory are intact in dyslexia (Liberman, Shankweiler, Orlando, Harris, & Berti, 1971; Vellutino, Pruzek, Steger, & Meshoulam, 1973; Vellutino, Smith, Steger, & Kamin, 1975). For example, the observation that dyslexics seem to have erratic eye-movements when reading, such as repeating fixations and frequently jumping backwards in the text, can be regarded as a consequence of, rather than a cause of, reading problems (Rayner, 1985a; Vellutino, 1978).

However, the perceptual deficit hypothesis has experienced a renaissance in recent years. A number of neuropsychological findings suggest that the

magnocellular pathway of the visual system, which handles fast, low contrast stimuli, might be impaired in dyslexia, whereas the slow and relatively contrast insensitive parvocellular pathway might be intact (Lovegrove, Garzia, & Nicholson, 1990; Livingstone et al., 1991; Slaghuis & Lovegrove, 1984; Stein & Talcott, 1999). For example, Slaghuis and Lovegrove (1984) suggested that visible persistence of previous fixations makes reading difficult for dyslexics. It has also been suggested that reading disabled children show a perceptual deficit in handling rapidly presented auditory stimuli (Tallal, 1980; Tallal, Miller, & Fitch, 1993), but these results need not reflect auditory perceptual deficits and could be explained by an imperfect phonetic module (Liberman, 1999; Mody, Studdert-Kennedy, & Brady, 1997).

Today, most researchers seem to agree that phonological deficits constitute the main underlying cause of the word decoding difficulties in developmental dyslexia (Bruck, 1992; Elbro, Borstrøm, & Petersen, 1998; Fletcher et al., 1994; Rack et al., 1992; Stanovich & Siegel 1994; Wimmer, Mayringer, & Landerl, 1998). This is therefore in line with the definition proposed by Høien and Lundberg (1992, p. 37): "dyslexia is a disruption in the decoding of the written language, caused by a defect in the phonological system".

There is very strong empirical evidence that phonological skills are critical in learning to read (see Share & Stanovich, 1995, for a review). Phonological awareness, that is, the ability to explicitly reflect on the sound structure of language, has also proven to be a good predictor of early reading acquisition (Goswami & Bryant, 1990; Lundberg, Olofsson, & Wall, 1980; Wagner & Torgesen, 1987). Furthermore, a great number of studies have demonstrated that developmental dyslexics perform below normal on various measures of phonological processing (Rack et al., 1992; Snowling, 1981; Stanovich, 1988b).

In order to obtain evidence for a causal relationship between phonological processing skills and reading ability, longitudinal intervention studies have been conducted. It has been shown that training in phonological (or phoneme) awareness can improve the phonological awareness and the reading skills of young children (Ball & Blachman, 1988; Lundberg, Frost, & Petersen, 1988; Schneider, Ennemoser, Roth, & Kuspert, 1999; Torgesen, Morgan, & Davis, 1992). Other studies indicate that phonological interventions in which the phonological tasks are explicitly linked to the orthography of written language might be even more effective for beginning readers (Bradley & Bryant, 1983; Cunningham, 1990; Hatcher,

Hulme, & Ellis, 1994). However, it should be noted that the reported effect sizes on reading ability were not always large and a number of methodological shortcomings have been identified in these intervention studies (Troia, 1999). The intervention studies have also typically been conducted on either young children with no apparent reading difficulties or on children who were in an early stage of reading development. Thus, these studies have not been specifically directed at those children most in need of intervention, that is, children who have lasting and severe difficulties in acquiring reading skills. The purpose of study V in the present thesis was to examine the effects of a phonological intervention on children in grade 4 with established reading difficulties.

In the introduction, I stated that the existence of neurological and genetic factors in developmental dyslexia is an empirical question and now I will present some of the main empirical findings.

Studies on autopsied brains of dyslexics have resulted in two main findings. The first deals with cerebral asymmetry. The planum temporale, a region on the upper surface of the temporal lobe, is asymmetric (of different sizes in the two hemispheres) in approximately two-thirds of the whole population (Galaburda, 1999). On the other hand, in most autopsied dyslexic brains, the planum temporale was found to be symmetric (Galaburda, 1994; Galaburda et al., 1985). This finding has also been replicated by studies employing magnetic resonance imaging (MRI) on living dyslexics (Hynd et al., 1990; Larsen, Høien, Lundberg, & Ødegaard, 1990; Morgan & Hynd, 1998). For example, in the study by Larsen et al. (1990), symmetric plana temporale were found in 70% of the dyslexic subjects, whereas only 30% of the controls exhibited symmetry. Larsen et al. (1990) also reported that all dyslexics with pure phonological deficits in reading had symmetric plana temporale.

The second main finding from autopsy studies is the presence of minor cortical malformations, termed ectopias, in dyslexic brains (Galaburda et al., 1985). Such brain "warts" have been found in both auditory and visual areas of the perisylvian cortex, including the classical Broca's and Wernicke's language areas (Galaburda, 1994). Galaburda (1994, p. 136) suggests that "symmetry in the presence of ectopias, as is the case in dyslexic brains, is likely to be associated with fundamental changes in the functional properties of networks participating in perceptual and cognitive activities." However, the exact locations and numbers of ectopias varied between the dyslexic brains, suggesting that, even if dyslexia has a neurological basis, individual variations in the severity and manifestations of the difficulties are to be expected. Interestingly, animal studies on "learning disabled"

ectopic mice demonstrate that the presence of neurological malformations does not imply that environmental factors cease to be important. On the contrary, the learning abilities of ectopic mice were significantly improved if they were reared in enriched environments (as compared to standard cages). In fact, ectopic mice reared in enriched environments seemed to compensate for their neurological impairments and performed on par with enriched non-ectopic mice on a complex spatial task (Schrott et al., 1992).

The pioneers in the field of reading disability research have already hypothesised that dyslexia is heritable (cf. Pringle Morgan, 1896). A large number of empirical studies support this hypothesis (Cardon et al., 1994; DeFries & Light, 1996; Hallgren, 1950; Olson et al., 1989; Pennington, 1991). Studies using data from identical and fraternal twins have obtained heritability estimates (the amount of variance in reading that can be attributed to genetic factors), of 50-60% (DeFries & Fulker, 1985; DeFries & Light, 1996; Pennington, 1991). Several studies have localised a gene for reading disability on chromosome 6, but other possible localisations have also been identified (Cardon et al., 1994; Fagerheim et al., 1999; Grigorenko et al., 1997). The different proposed localisations might suggest genetic heterogeneity in developmental dyslexia. Fagerheim et al (1999, p. 1) state that: "genetic heterogeneity is likely and could provide some explanation for the high frequency of dyslexia, but has not yet been clearly shown. Furthermore, the complexity of the reading process also suggests that many genes may be involved." Of course, what is inherited is not reading disability or dyslexia itself. There can be no specific "reading genes" solely devoted to the process of reading, because reading is a cultural artefact, just like driving a car. The functions that are in fact inherited are more basic cognitive and perceptual abilities which are critical for the process of reading. Behavioural–genetic studies suggest that phonological ability is the most likely mediator of genetic influences on reading skill. A lower but significant heritability has also been found for orthographic decoding skills (Olson et al., 1989; Stevenson, 1991).

To summarise, developmental dyslexia seems to be constituted by difficulties in transforming the code of the written language into comprehensive entities. These difficulties in word decoding are assumed to be caused mainly by phonological deficits which impair the acquisition of both phonological and orthographic word decoding skills in the dyslexic child. Higher mental activities, such as understanding, are not assumed to be directly affected in dyslexia, but deficient word decoding skills might lead to an impaired reading comprehension. There is strong evidence of underlying

neurological and genetic factors associated with dyslexia, but they will always interact with environmental factors in the development of reading skills.

4.2 Reading disabilities including comprehension deficits

In the previous section, many findings concerning developmental dyslexia have been discussed. This type of reading disability is also sometimes referred to as specific reading disability. However, not all reading disabled people fit a specific and narrow definition of the causes and manifestations of reading difficulties. Not all reading difficulties are caused by congenital, neurological impairments that specifically disturb the phonological system and result in problems with word decoding. Also, whereas biological factors seem to be associated with developmental dyslexia, other types of reading disability might be more strongly associated with environmental factors, such as limited exposure to written language or inadequate reading instruction. Furthermore, cognitive deficits other than deficits in phonological processing, as well as a more general developmental delay, may also lead to reading difficulties. The manifestations of these types of reading disability need not be restricted to word decoding deficits, but could also include the other component of reading: comprehension (Aaron, 1997, see also section 3.1).

In the framework suggested by Aaron (1997), there are three basic types of reading disability. Developmental dyslexia, or specific reading disability, is constituted by deficits in word recognition but with intact comprehension. In addition, there are two types of reading disability which include comprehension deficits: those who have specific deficits in comprehension but intact word recognition skills and those who have problems with both comprehension and word recognition.

Although research on reading disabilities seems to have focused on developmental dyslexia, some recent studies have examined the group of poor readers characterised by specific comprehension deficits (Nation & Snowling, 1998a; 1998b; Oakhill, 1982; Stothard & Hulme, 1992). These studies have shown that poor comprehenders have adequate phonological skills but weak receptive language skills and a low verbal IQ (Stothard & Hulme, 1992), show less contextual facilitation than normal readers, who, in turn, show less contextual facilitation than dyslexic children (Nation & Snowling, 1998a). They also tend to have difficulty in reading words that are typically read with support from semantics (Nation & Snowling, 1998b). From these studies, it should be clear that children with specific deficits in

comprehension differ from dyslexic children in many aspects. In fact, they often show an opposite pattern of results compared to dyslexics (e.g., Nation & Snowling, 1998a).

However, if we turn to the group of globally poor readers, who have difficulty with both word decoding and comprehension, the relation to developmental dyslexia becomes more complicated. Globally poor readers are sometimes referred to as garden-variety poor readers (Stanovich, 1988b), and the term itself illustrates the heterogeneity of this group. Because of the lack of any specific deficits, it is very difficult to provide any precise definition of this type of reading disability.

There is also an ongoing debate concerning the issue of specificity in developmental dyslexia. Since there is now strong evidence that developmental dyslexia is characterised by poor word recognition skills mainly caused by phonological deficits (see section 4.1), it could be argued that all poor readers who fulfil these criteria should be included in the dyslexic category, regardless of whether they have other difficulties (see Stanovich, 1996). However, the call for a more inclusive definition of developmental dyslexia has often been associated with a more specific critique, focused on the inclusion of the concept of intelligence in the definition (Stanovich, 1996; Siegel & Himel, 1998). According to traditional IQ-discrepancy based definitions, there has to be a discrepancy between the IQ score and the reading ability in order for a poor reader to be categorised as dyslexic. The discrepancy criterion can be criticised on several grounds, however (see study I of this thesis). For example, there is only a moderate correlation between reading ability and intelligence, and the causal relation between the two concepts is not clear (Aaron, 1997; Stanovich, 1986, 1996). Furthermore, reading disabled children with high and low IQs perform very similar on various measures related to reading (Ellis, McDougall, & Monk, 1996; Fletcher et al., 1994; Samuelsson et al., 1999; Stanovich & Siegel, 1994).

However, it should be noted that even if the concept of intelligence is kept out of the definition, it is still not clear just how specific the reading difficulties have to be in developmental dyslexia, or what the requirements on higher level processes should be. Comprehension is more directly related to the process of reading than is the broader concept of intelligence. Therefore, it is quite possible to both criticise the IQ-discrepancy criterion and simultaneously propose that a classification of reading disability should be based on the two components word decoding and comprehension (cf. Aaron, 1997).

4.3 Surface and phonological types of reading disability

Another basis for identifying subgroups of reading disability is to examine the relative strength in using the two main word decoding strategies: orthographic and phonological. Contrary to discrepancy-based classifications, this classification is very closely linked to the process of reading itself (see section 3).

The terms surface and phonological dyslexia were originally used to describe cases of acquired dyslexia, that is, specific difficulties in using one of the two word decoding strategies as a consequence of brain injury or disease. Some acquired dyslexics, termed phonological dyslexics, show a selective difficulty in using the phonological word decoding strategy while their orthographic word decoding skills are nearly intact (Dérouesné & Beauvois, 1979; Patterson, 1982). Other cases, termed acquired surface dyslexics, are characterised by selectively impaired orthographic word decoding in the presence of nearly intact phonological word decoding (Newcombe & Marshall, 1985; Shallice & Warrington, 1980).

Related to these cases of acquired dyslexia, cases of developmental surface dyslexia (Coltheart et al., 1983; Holmes, 1973; Samuelsson, 2000; Samuelsson, Bogges, & Karlsson, 2000) and developmental phonological dyslexia (Snowling & Hulme, 1989; Temple & Marshall, 1983) have been reported. If surface and phonological types of reading disability were rare and exceptional in the whole population of reading disabled individuals, this classification might not be very useful. However, Castles and Coltheart (1993) developed a regression-based method to identify surface and phonological subgroups in the population of reading disabled children. From this study and other studies using similar procedures, it is clear that the relative skills of using orthographic and phonological word decoding vary considerably among reading disabled children (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997).

Although the regression-based method for identifying phonological and surface types of reading disability seems promising, there are still some critical questions that remain to be answered in this field of research. One question regards the causes of the differences. It seems that the phonological subtype could be explained by underlying deficits in the phonological system, while the surface subtype might reflect a general developmental delay rather than resulting from a cognitive deficit (Manis et al., 1996; Samuelsson, Finnström, Leijon, & Mård, 2000; Stanovich, et al., 1997). Recent behavioural-genetic studies also suggest that the two subgroups differ

in terms of heritability (Castles et al, 1999; Gayan, Forsberg, & Olson, 1994). Significant heritability of reading deficits was found for both subgroups, but the genetic contribution was much larger in phonological dyslexics than in surface dyslexics (Castles et al., 1999). These results support the hypothesis that there is a stronger environmental contribution in the surface type of reading disability. The possible cognitive and environmental causes of the phonological and surface types of reading disability were examined in the third and fourth study of the present thesis.

Another question that needs to be addressed in future studies concerns the stability of the subgroups over time. If a large number of children would move from one subgroup to the other when repeating the subgrouping procedure after some time, this would cast doubts on the reliability and validity of this classification procedure (cf. Stanovich et al., 1997).

5. OBJECTIVES

The general aim of the present thesis is to describe and analyse individual differences among reading disabled children. In order to be able to develop adequate and more individually adapted educational interventions, there is a need to gain more knowledge concerning varieties of reading disability.

A critical evaluation of the validity of current definitions and classifications of reading disability and a search for theoretically and empirically sound classifications would be a necessary first step in the analysis. The aim of such an evaluation would be to identify which aspects of reading disability could be used as a basis for classification, and which aspects do not seem to offer a good foundation for this purpose. I agree with Aaron (1997) in that one criterion should be that the classification is outcome-based and that it suggests different interventions for different groups of poor readers. Thus, study I of the present thesis is a critical examination of traditional definitions of dyslexia which are based on the discrepancy between intelligence and reading ability. This theoretical study is also an attempt to identify alternative classifications of reading disability.

The possible causes of critical variations among reading disabled children then need to be examined. Different causes may suggest different interventions. Here, the complexity of reading disability necessitates that developmental (see section 3.2), cognitive (see sections 3 and 4), and environmental (see section 2.3) aspects are considered in the analyses. Developmental aspects of word decoding skills are focused in study II of this thesis. Study III examines the possible associations between implicit memory and word

decoding skills. Study IV examines both cognitive and environmental factors potentially associated with orthographic and phonological word decoding skills.

Finally, the validity of the proposed classification system and the resulting subgroups of reading disabled children should be examined. A direct way of assessing whether the proposed classification is outcome-based or not is to conduct a longitudinal intervention study. Therefore, in study V of the present thesis, differences between groups in the effectiveness of a phonological intervention is examined.

Variations in the effectiveness of a particular intervention, interpreted in light of possible causes of different varieties of reading disability, could provide suggestions for more adequate interventions for different groups of reading disabled children. Although the primary purpose of the present thesis is to gain more knowledge concerning varieties of reading disability, the empirical findings may also have theoretical implications for the more general fields of reading research and cognitive psychology. This should be regarded, however, as an additional bonus of conducting research in the field of reading disabilities, rather than the main objective of the present thesis.

6. SUMMARY OF THE STUDIES

6.1 Study I

In this article the inclusion of the concept of intelligence in the definition of dyslexia was critically examined. A number of theoretical problems and practical consequences of such an inclusion were discussed.

According to the IQ discrepancy criterion, an individual should only be regarded as dyslexic if there is a discrepancy between his or her actual reading ability and the potential reading ability as estimated by the IQ score. Furthermore, the actual reading ability has to be below normal, whereas the IQ score has to be within or above the normal range (Aaron, 1997).

We identified several problems and paradoxes associated with the IQ discrepancy criterion. First, we pointed out that intelligence is a fuzzy concept in itself. There is little general agreement on what mental capabilities should be included in the concept (Sternberg, 1990; Sternberg & Detterman, 1986). Secondly, intelligence is only moderately correlated with reading ability, and the causal direction between the two variables is not clear (Aaron, 1997; Stanovich, 1986, 1996). Thirdly, we pointed to groups that

will be excluded from the dyslexic category even if they also have word decoding deficits stemming from underlying phonological deficits. These groups included dyslexics who are able to compensate for their word decoding deficits (Snowling & Nation, 1997), poor readers with low IQ (Siegel, 1988; Stanovich, 1996), children from low socio-economic backgrounds (Siegel & Himel, 1998), and children with very low birth weight (Samuelsson et al., 1999).

We also identified groups that will be included in the dyslexic category, even if the cause of their reading difficulties is completely different from the underlying phonological deficits assumed to be causally related to dyslexia. Thus, groups who are poor readers because of limited experience with written language would be at risk of being classified as dyslexics even if they have no underlying constitutional or cognitive deficits (Samuelsson et al, in press; Stanovich & West, 1989; Svensson, Lundberg, & Jacobson, in press; Vellutino et al, 1997).

Our final, critical remark on the IQ discrepancy criterion was that poor readers of high and low IQs do not seem to differ on a number of measures related to the process of reading (Ellis, McDougall, & Monk, 1996; Fletcher et al, 1994; Stanovich & Siegel, 1994). This finding implies that the discrepancy criterion is not an outcome-based definition and does not suggest any particular intervention for different groups of poor readers (cf. Aaron, 1997).

Many of these problems and paradoxes stem from the fact that the cause of the reading difficulties is completely ignored in the IQ discrepancy definition of dyslexia (Tønnessen, 1997). In this article we refer to a large number of empirical studies which have provided evidence for the critical role of phonological deficits in dyslexia (cf. Share & Stanovich, 1995). This suggests that the status of the phonological system should be focused on in classifications of reading disabilities.

In conclusion of this study, two alternative classifications of reading disability were suggested. One is based on the two components of reading: word recognition and understanding, where understanding is a more specific concept than IQ and also more closely related to the process of reading (Aaron, 1997). Another, more outcome-based classification would be to examine the reliance on, as well as the skill in using, the two main word decoding strategies: orthographic and phonological decoding. The way that a child decodes words seems to be related to the effectiveness of a particular training program (see study V of this thesis).

6.2 Study II

The general purpose of this study was to examine the development of phonological and orthographic word decoding skills in young readers. The study examined the relation between word decoding skills and reading comprehension for children who varied both in chronological age and in their level of word decoding skill.

According to most models of acquisition of word decoding skills, children first become proficient in using phonological decoding and then shift gradually toward using orthographic decoding (Ehri, 1987; Høien & Lundberg, 1988). In order to assess the relative contribution of phonological and orthographic skills in text reading it is not sufficient to study skills in decoding words presented in isolation. In the present study, we therefore examined the relative contribution of orthographic and phonological decoding skills to reading comprehension.

Sixty 8-year-old children, termed novice readers, and sixty 10-year-old children, termed experienced readers, were randomly selected from ten different schools. In contrast to the other empirical studies of the present thesis, these children had no apparent reading difficulties. However, variations in their reading skills were at the focus of the study. Thus, within each age group, new groups of children were formed based on their level of phonological and orthographic word decoding skills.

The test battery included two measures of reading comprehension (Malmquist, 1977), which were used to form an index of the critical dependent variable, and measures of orthographic and phonological word decoding (Olofsson, 1999; based on the design of Olson, Kliegl, Davidson, & Foltz, 1985).

The results replicated previous findings that children rely mainly on phonological word decoding early in their reading development, and that there is a gradual shift to more reliance on the orthographic word decoding strategy (Ehri, 1987; Frith, 1985; Juel et al., 1986). The results of multiple regression analyses revealed that phonological and orthographic decoding skills together accounted for 62% of the variance in reading comprehension for novice readers and 45% of the variance in reading comprehension for experienced readers. Orthographic word decoding skill was a significant predictor of reading comprehension, both for novice and experienced readers. Phonological word decoding skill was a significant predictor of reading comprehension only for novice readers.

The finding that orthographic decoding predicted reading comprehension for novice readers indicates that some novice readers had already begun to acquire orthographic skills in their word decoding. When a new regression analysis was performed on less skilled novice readers only (i.e., the 30 children who performed below the median on reading comprehension), orthographic word decoding was no longer a significant predictor of reading comprehension.

There were also statistically significant interactions between level of word decoding skill and reading skill (i.e., the groups of novice and experienced readers) on reading comprehension, both for orthographic and phonological word decoding. The differences in reading comprehension as a function of both orthographic and phonological decoding skills were larger for novice readers than for experienced readers. Thus, in younger and less skilled readers, variations in word decoding skills seem to be more important in explaining differences in reading comprehension than in more experienced and skilled readers.

The results were interpreted as supporting the general core of developmental models (cf. Høien & Lundberg, 1988), in which there is a gradual shift from phonological to orthographic decoding of words. It was also suggested that the link to reading comprehension in this study helped to generalise models of the development of word recognition skills to text reading and reading comprehension. Finally, the finding that phonological word decoding skill was a strong predictor of reading comprehension for novice readers, especially for those who performed below the median on reading comprehension, suggested that phonological training should also be considered for children who have already received one or two years of formal reading instruction in school.

6.3 Study III

The third article combined recent findings regarding surface and phonological subtypes of reading disability, as well as findings in memory research suggesting visual and auditory perceptual representation systems (PRS) in implicit memory. The general purpose was to examine how visual and auditory priming for words interact with skill in using the orthographic and phonological word decoding strategies.

Most models of the development of word decoding skills suggest that both phonological and orthographic information is involved in word recognition (Castles & Coltheart, 1993; Ehri, 1987; Seidenberg & McClelland,

1989). However, it is possible to identify children who show better phonological than orthographic word decoding skills, and vice versa. An impaired phonological, relative to orthographic, word decoding ability is labelled phonological dyslexia, and the opposite pattern is labelled surface dyslexia (Castles & Coltheart, 1993). Dual-route models of reading explain dissociations between phonological and orthographic skills by proposing that in phonological dyslexia, the sublexical route (which relies on grapheme–phoneme conversion) is selectively impaired. In surface dyslexia, the lexical route from print to meaning is assumed to be selectively impaired (Coltheart et al., 1993; Castles & Coltheart, 1993). Single-route models have proposed that phonological dyslexia can be explained by phonological weaknesses, affecting the use of orthography to phonology conversions (Seidenberg & McClelland, 1989; Manis et al., 1996). Surface dyslexia has been accounted for by suggesting a general delay in learning how orthography maps phonology (Manis et al., 1996).

Study III attempted to answer two questions related to subtypes of reading disability. First, is it possible to gain independent evidence that orthographic and phonological word decoding skills can be simultaneously impaired (Manis et al., 1996)? Second, is it possible to identify an underlying cognitive deficit in surface dyslexia (Castles & Coltheart, 1993; Ellis, McDougall, & Monk, 1996)?

In order to answer these questions we turned to recent findings in the field of memory research, which have revealed striking dissociations between different memory systems and dissociations between the visual and auditory word form systems in implicit memory (Schacter et al., 1990). According to the PRS account (Schacter & Church, 1992; Tulving & Schacter, 1990), traditional explicit tests of retention, such as recall or recognition, are assumed to tap the episodic memory system, whereas implicit memory represents priming of pre-semantic perceptual representation systems. Schacter et al. (1990) provides evidence of a functional dissociation between visual and auditory priming in a letter-by-letter reader. Their findings suggest that visual perceptual priming taps a visual word form system, while auditory priming taps an auditory word form system. Thus, we hypothesised that children with a surface type of reading disability would show less visual compared to auditory priming for words. Phonological type children would be expected to show less auditory compared to visual priming. Children with both orthographic and phonological word decoding deficits would be expected to show low levels of both visual and auditory priming.

Thirty-six children with reading disabilities participated in the study and they were 9 to 15 years old. Most had been diagnosed as developmental dyslexics and all received special instruction in reading at the time of the study. Since IQ scores were not available for all children, the term "poor readers" was used instead of "dyslexics".

Orthographic and phonological word decoding skills were assessed by two timed pen and paper tests (Olofsson, 1999; Olson et al., 1985) and three subgroups of children were identified by means of a standard score procedure. Discrepancy scores between orthographic and phonological skills were first calculated. Based on a cut-off score of one standard deviation above or below the mean, six children were low in phonological, relative to orthographic, skill (the phonological subgroup). However, one child was excluded from this subgroup because of an orthographic skill clearly below the mean. Five children were low in orthographic, relative to phonological, skill (the surface subgroup). Twenty-five children did not dissociate in their word decoding skills and were denoted the mixed subgroup. Comparisons with age-matched controls revealed that the subgroups were at least two years behind in orthographic decoding, phonological decoding, or both.

Explicit memory was examined by free recall, both for visually and auditorily presented words. Visual implicit memory was assessed by a word stem completion test and auditory implicit memory was assessed by an auditory identification test. A letter matching test (Posner et al., 1969) was used to control for possible differences in visual perception, and a verbal fluency test was included to control for possible semantic differences.

No differences in visual perception or verbal fluency were found between the subgroups and there were no differences on the measures of visual and auditory explicit memory. However, in accordance with our predictions, the results provided evidence of a double dissociation, such that surface type children showed more auditory than visual priming, whereas the phonological subgroup produced more visual than auditory priming. The mixed subgroup showed low levels of both visual and auditory priming. The findings of this study therefore suggest that visual and auditory implicit memory are candidates to provide independent support for underlying cognitive deficits in subgroups of poor readers. Since perceptual priming is not mediated by explicit retrieval strategies, the results suggested that deficits in either phonological or orthographic word decoding reflect underlying cognitive weaknesses rather than strategic differences. The impaired auditory priming in the phonological subgroup is consistent with the view that the phonological type of reading disability is associated

with underlying phonological processing deficits. The impaired visual priming found in the surface subgroup suggests that one of their primary problems might be located in the visual word form system.

In conclusion, the results showed that it is possible to dissociate orthographic from phonological word decoding deficits, and that both routes can be simultaneously impaired.

6.4 Study IV

The fourth study built on the results found in study III. One goal was to replicate the finding of an interaction between visual and auditory priming and orthographic and phonological word decoding skills. In addition to cognitive measures, we also included measures of print exposure in this study. Print exposure could very likely affect the development of word decoding skills (Castles et al., 1999; Clay, 1987; Stanovich et al., 1997). In particular, it has been suggested that surface dyslexia may result from less severe phonological deficits in combination with limited exposure to print (Castles et al., 1999; Stanovich et al., 1997).

A different method for the subgrouping procedure was used as compared to study III. In study IV, we used a method based on regression analysis developed by Castles and Coltheart (1993) and modified by Manis et al (1996) and Stanovich et al (1997). In this subgrouping procedure, two regression analyses are first performed on control subjects, with the two variables being orthographic and phonological word decoding skill. The regression lines with confidence intervals are then superimposed on the corresponding scatter plot of the reading disabled subjects. Surface and phonological type subjects are those subjects who fall below the confidence limit of the relevant scatter plot.

Previous studies indicate that the choice of control group is critical for the outcome of this procedure. It has been argued that comparisons should be made with younger, reading-level matched controls rather than with age matched controls (Manis et al., 1996; Stanovich et al., 1997). Findings also suggest that when reading-level controls supply the regression lines instead of age matched controls, the number of surface type subjects is reduced (Manis et al., 1996; Stanovich et al., 1997).

In study IV, both age matched controls (29 children, with a mean age of 11 years, 0 months) and reading-level controls (26 children, with a mean age of 8 years, 11 months) were used for comparison. Fifty-three reading disabled children with a mean age of 11 years, 2 months participated in the study. The

reading disabled children all received special instruction in reading because of reading difficulties at the time of the study. Children with gross neurological impairments, sensory deficits, and children who did not speak Swedish as their first language were excluded from the sample.

The test battery included measures of reading ability (Malmquist, 1977), listening comprehension, visual and auditory explicit memory (i.e., free recall), visual and auditory implicit memory (i.e., stem completion and word identification), arithmetic, computerised tests of orthographic and phonological word decoding (Olofsson, 1999; Olson et al., 1985), and semantic and phonological verbal fluency. In addition to the cognitive measures, a questionnaire containing 10 items about reading habits and print exposure were completed by the children.

The results of the regression-based subgrouping procedure revealed that when the age matched controls supplied the regression lines, 11 phonological type, 30 surface type, and 12 mixed type subjects were identified. When the regression lines were instead supplied by the reading-level controls, the number of phonological type subjects increased to 18, the number of surface type subjects decreased to 10, and the number of mixed type subjects increased to 25. These results replicate previous findings that the choice of control group is critical when using this subgrouping procedure and that the number of surface type subjects is reduced when comparisons are made with reading-level matched controls instead of age matched controls (Manis et al., 1996; Stanovich et al., 1997). Thus, the pattern of orthographic and phonological word decoding skills found in surface type children is more similar to the pattern of younger children than that found in age matched children. This, in itself, suggests that the surface type of reading disability might be characterised as a developmental delay.

The results of the cognitive measures revealed that the entire sample of reading disabled children performed below age matched controls on measures of reading skills, explicit memory, listening comprehension, arithmetic, and semantic verbal fluency. Thus, this sample of reading disabled children would not satisfy a narrow definition of developmental dyslexia. Comparisons between the individual subgroups revealed that phonological type children only showed a specific deficit in phonological word decoding. Surface type children performed below the other groups on most cognitive measures, including visual priming for low frequency words, and they also reported fewer books at their homes (suggesting an association to limited print exposure). A highly significant correlation was also obtained between orthographic decoding and the number of books at

home. This pattern of results supported the hypothesis that the surface type of reading disability can be characterised as a general developmental delay, and that environmental factors might contribute more to this type of reading disability than to the phonological type.

6.5 Study V

The purpose of this longitudinal intervention study was to examine the effects of a strictly phonological intervention on the reading skills of reading disabled children in grade 4 (i.e., 10-11 years old). In addition to the examination of average improvements in reading, we examined possible explanations of differences in the effectiveness of the intervention.

Previous intervention studies have shown that phonological training can improve the phonological awareness and reading skills of young children (Bradley & Bryant, 1983; Hatcher et al., 1994; Lundberg, et al., 1988). However, the children who participated in these studies were quite young (7 years old at the most). Therefore, these interventions have not been directed towards children who experience lasting difficulties in acquiring reading skills and who are subject to special instruction for reading in school. In study V we wanted to examine whether strictly phonological training would also be effective for older children who were in need of special instruction for their reading difficulties.

We selected 33 children in grade 4 who received special instruction in reading according to our phonological training program (the phonological training group). Three control groups were also included in the study: 16 poor readers in grade 4 who would continue to receive regular special instruction during the intervention (grade 4 controls), 16 subjects who were matched with the two previous groups on reading ability, but who were two years younger (grade 2 controls), and finally, 83 children in grade 4 with no apparent reading difficulties (normal readers).

The children in the phonological training group received instruction according to a strictly phonological program (Gustafson & Samuelsson, 1998) over two semesters. The training program included seven different types of phonological exercises: rhymes, position analysis, subtraction or addition of sounds, segmentation, blending, and accentuation. The phonological training was carried out by nine experienced special instruction teachers in the children's normal school settings.

On three occasions (before, in the middle of, and after the intervention), the experimenter visited the schools and administered a comprehensive test

battery to all participating children. The test battery consisted of measures of reading ability (Malmquist, 1977), orthographic and phonological word decoding skills (Olofsson, 1999; Olson et al., 1985), phonological awareness, visual perception, and semantic memory.

The results replicated findings that phonological training improves the phonological awareness of children (Lundberg et al., 1988; Hatcher et al., 1994). However, the increase in phonological awareness was only accompanied by an increased reading ability for some children. Interestingly, the differences in response to the intervention seemed to be related to the use of word decoding strategies. The results of three separate regression analyses indicated that orthographic, but not phonological, word decoding contributed to text reading performance for children who resisted the intervention and failed to improve their reading skills (this held true before, during, and after the intervention). Thus, it seems that in order to benefit from a strictly phonological intervention, the child has to rely on the phonological word decoding strategy to some extent. In order for a phonological intervention to be successful for resistant children, it might be necessary to include explicit links between sounds and letters in the training program (see Bradley & Bryant, 1983; Hatcher et al., 1994).

6.6 Summary of the findings

In the first study, a number of serious problems resulting from the inclusion of IQ in the definition of developmental dyslexia were identified. We proposed that a classification of reading disability should acknowledge the causes of reading disability and that it should be outcome-based; that is, it should provide a basis for suggesting relevant interventions for different groups of poor readers (cf. Aaron, 1997). One of the proposed models was based on the two components of reading: word recognition and comprehension (Aaron, 1997). The other alternative was based on the two main word decoding strategies: orthographic and phonological word decoding. Different aspects of these word decoding strategies were analysed in the remaining four empirical studies of the thesis.

The second study examined developmental aspects of phonological and orthographic word decoding skills. This study replicated previous findings that there is a gradual shift from phonological to orthographic word decoding (Ehri & Wilce, 1987; Juel et al., 1986). The results of regression analyses also suggested that this shift could be generalised to text reading. However, since phonological word decoding contributed to text reading

performance for novice readers, we suggested that phonological interventions might also be considered for children with one or two years of formal reading instruction.

The third and fourth study examined the relationship between orthographic and phonological word decoding skills and visual and auditory implicit memory for words. In the third study, a double dissociation was obtained, revealing that surface type children showed more auditory than visual priming, whereas the phonological subgroup produced more visual than auditory priming. These results suggested that visual and auditory implicit memory may provide independent support for underlying cognitive deficits in the surface and phonological types of reading disability.

The fourth study did not reveal such a double dissociation. However, it should be noted that a different, regression-based subgrouping procedure was used in study IV. A slightly different sample of reading disabled children and slightly different word decoding tests were also used. The results of study IV suggested that the phonological type of reading disability might be characterised by specific deficits in phonological decoding. The general pattern of results here also suggested that the surface type might be characterised as a general developmental delay. The results revealed a visual implicit memory deficit in surface type children, but only for low frequency words. The results also showed that surface type children tend to report fewer books in their homes, suggesting that there might be a stronger environmental contribution in this type of reading disability.

Finally, the results of study V suggested that the relative reliance on orthographic and phonological word decoding in text reading has implications for the effectiveness of an educational intervention. The results showed that poor readers who received a strictly phonological intervention improved their phonological awareness, but this did not generally transfer to improved text reading. Instead, there was considerable individual variation in reading progress among the poor readers. Some children seemed to benefit from the intervention, while other children did not show any improvement in text reading (in spite of a steady increase in phonological awareness). Only one difference between improved and resistant readers was found: where improved readers seemed to rely on both orthographic and phonological word decoding in text reading, resistant readers seemed to rely only on orthographic word decoding. Note that this difference between improved and resistant readers concerned the relative contribution of the two word decoding strategies to text reading performance and not the relative skill in using the two strategies. Therefore, the resistant

readers of study V should not be confused with those that exhibit the phonological type of reading disability examined in study III and IV.

7. DISCUSSION

7.1 General discussion

In the first study, we critically examined the inclusion of general intelligence in the definition of developmental dyslexia. Based on recent findings, as well as from our own empirical studies, it was concluded that this procedure of classifying reading disabled children into dyslexic and non-dyslexic categories should be replaced by classifications which better acknowledge the manifestations, as well as the causes, of different reading disabilities (cf. Tønnessen, 1997).

There is strong empirical evidence that developmental dyslexia is associated with phonological deficits (e.g., Bruck, 1992; Rack et al., 1992; Stanovich & Siegel, 1994), stemming from underlying neurological impairments (Galaburda et al., 1985; Larsen et al. 1990). The primary manifestation of phonological deficits in reading seems to be poor word decoding skills (Perfetti, 1985; Share & Stanovich, 1995; Stanovich, 1986; Vellutino & Scanlon, 1987). These findings seem to provide a more solid basis for a definition of developmental dyslexia than the discrepancy between intelligence and reading ability (cf. Siegel, 1988; Stanovich, 1996).

The conceptual problems and confusions in this field of research might, in part, stem from the fact that different causes of reading disability interact with one another. For example, environmental factors will always influence the reading skills of a particular child, regardless of whether this child is dyslexic or not. It seems questionable to exclude a child from the dyslexic category just because this child happens to be unfortunate in other respects as well, such as having a poor socio-economic background or by having inappropriate reading instruction in school (see the definition by The World Federation of Neurology cited in section 4.1). Also, it is not clear just how specific the cognitive deficits have to be in order for a child to be categorised as dyslexic. A child with multiple problems would certainly need extra educational resources in order to promote his or her reading skills. Additionally, as long as the problems include underlying phonological deficits, such a child would be expected to benefit from training programs designed for dyslexic children. An intervention focused on improving cognitive abilities (i.e. phonological awareness) would not preclude other simultane-

ous interventions aimed at other possible causes of the child's reading difficulties. The main problem with this seems to be distinguishing between different causes of reading difficulties. This calls for valid diagnostic tools focused on the specific deficits associated with developmental dyslexia.

The need to consider the multi-dimensional nature of reading disabilities has been emphasised by several researchers (Frith, 1999; Lundberg & Høien, 1997; Van der Leij, 1997). The three-level framework proposed by Frith (1999) will be used in the following discussion concerning varieties of reading disability.

Frith (1999) suggests that a framework of dyslexia should include three levels of analyses: biological, cognitive, and behavioural. At all three levels, interactions with environmental factors occur. The biological level includes neuro-anatomical and genetic factors, the cognitive level refers to proposed causes related to information-processing mechanisms (i.e., cognitive hypotheses and theories), and the behavioural level refers to behavioural observations, such as test performance. Frith (1999) suggests that if these different levels of analyses are acknowledged, many misunderstandings and apparent paradoxes concerning the definition of reading disabilities disappear (see sections 4.1 and 4.2). The framework proposed by Frith (1999) bears similarities to the multi-dimensional model of impairments, disabilities, and handicaps previously presented in section 2.1 (WHO, 1980), and acknowledges the inherent complexity of the concept of reading disability (cf. Huey, 1908/1968).

On the behavioural level of analysis, the results of the present thesis suggest that variations in orthographic and phonological word decoding skills seems to be a useful basis for classifying varieties of reading disability (see study III and IV). Contrary to classifications based on the IQ-discrepancy criterion, this method is very closely associated with the process of reading itself. The distinction between surface and phonological types of reading disability also seems useful in generating new hypotheses concerning the influence of biological, cognitive, and environmental factors in different types of reading disability (see below). The results of study V suggest that behavioural observations should not be restricted to assessments of phonological and orthographic word decoding skills but should also include observations of the relative reliance on these two word decoding strategies in text reading.

On the cognitive level of analysis, the results of study III suggest that the surface type of reading disability might be associated with an underlying cognitive deficit in the visual perceptual representation system (Schacter et

al., 1990). These results do not reveal whether this deficit is constituted by poorer, and perhaps less distinct, visual representations or if the problem is associated with difficulties in accessing these representations (or even both types of problems). The existence of structural deficits and/or process deficits in the visual perceptual representation system of reading disabled children could be the subject of future empirical studies.

The results of study IV do not fully support the finding of a general deficit in the visual perceptual system of children with a surface type of reading disability. In study IV, surface type children showed reduced visual priming only for low frequency words. This result in itself indicates that environmental factors, such as exposure to print, might need to be taken into consideration in an explanation of the surface type of reading disability (Castles et al., 1999; Stanovich et al., 1997). Limited print exposure would be expected to have more pronounced negative effects on the perceptual representations of words that are seldom seen.

This interpretation was in part supported by the questionnaire data of study IV. Surface type children reported fewer books at their homes than both mixed type subjects and reading-level matched controls. Early, informal literacy socialisation can be expected to influence the general attitude towards reading (Gottfried, Fleming, & Gottfried, 1998), and a relatively limited exposure to print during childhood might result in delayed reading development (Braten, Lie, Andreassen, & Olaussen, 1999; Leseman & de Jong, 1998). Supporting this, study IV also revealed a highly significant correlation between the orthographic decoding variable and the reported number of books at home.

The results presented in studies III and IV regarding possible causes of the surface type of reading disability are not conclusive. However, they do suggest that the nature of the visual perceptual representation system, as well as the relationship between the visual PRS and print exposure, should be examined more closely in future research. It should also be noted that the results of both studies are in line with the hypothesis that the surface type of reading disability can be characterised as a general developmental delay (Manis et al., 1996), and that environmental factors, such as print exposure, are important in explaining this type of reading disability (Castles et al., 1999; Stanovich et al., 1997).

The failure in study IV to replicate the finding of impaired auditory priming in the phonological type of reading disability in study III might stem from differences in the samples of reading disabled children. In study III, most of the children had been diagnosed as dyslexics, suggesting specific

phonological deficits (see section 4.1). In study IV, the sample included a number of children who had more global deficits (see section 4.2) due to the fact that they performed below age matched controls on measures of semantic verbal fluency, explicit memory, and arithmetic. These results seem to be in line with the general idea behind the phonological-core variable differences model proposed by Stanovich (1988b), which states that where developmental dyslexics might have specific reading difficulties stemming from underlying phonological deficits, there is a continuum of the degree of specificity, and therefore, other reading disabled children have more general language and cognitive difficulties. However, the model by Stanovich (1988b) was based on the comparison of IQ-discrepant and non-discrepant reading disabled children and IQ was not assessed in our studies. In a more recent study, Stanovich and Siegel (1994) recognised that comparisons based on IQ did not reveal any distinct differences between groups within the word recognition module (see also Fletcher et al., 1994).

On the biological level of analysis, both behavioural–genetic and neurological findings provide links to behavioural findings and cognitive hypotheses regarding surface and phonological subgroups. Behavioural–genetic studies suggest that both phonological and orthographic decoding skills are heritable, but also that phonological skill shows higher heritability (Olson et al., 1989; Stevenson, 1991). In line with this, Castles et al. (1999) observed significant heritability of reading deficits for both surface and phonological dyslexics, with the genetic contribution being much larger in phonological dyslexics. These findings suggest that there is a stronger environmental contribution in the surface type of reading disability than in the phonological type.

Neurological findings, such as the tendency for symmetric plana temporale (see Galaburda et al., 1985; Larsen et al. 1990), are consistent with the existence of phonological deficits in developmental dyslexia. Also, the magnocellular deficit hypothesis suggests auditory as well as visual lower-level processing deficits in developmental dyslexia (Livingstone et al., 1991; Lovegrove et al., 1990; Slaghuis & Lovegrove, 1984). The magnocellular deficit hypothesis would be able to account for phonological and surface types of reading disability by assuming that the visual, as well as the auditory, magnocellular system can be selectively impaired (cf. Stein & Talcott, 1999).

To summarise, there are hypothesised cognitive factors associated with the phonological subtype (although the exact nature of these proposed phonological deficits is not clear at this point), as well as hypothesised

cognitive and environmental factors underlying the surface subtype. Findings on the biological level of analysis seem to be consistent with the distinction between phonological and surface types of reading disability. It also appears that this classification system has already proven useful for suggesting new hypotheses about varieties of reading disability.

However, it should be noted that both phonological and orthographic word decoding skills seem to be continuous and normally distributed variables and that arbitrary cut-off points are used to separate phonological type, mixed type, and surface type subjects from each other. Therefore, it is not suggested that these subgroups are discrete and homogeneous (see Murphy & Pollatsek, 1994; Stanovich et al., 1997) and findings should be interpreted with caution, especially due to the fact that it has yet to be demonstrated that the resulting subgroups are stable over time.

In addition to biological, cognitive, behavioural, and environmental aspects of reading disabilities, I would like to suggest that the developmental aspect also needs to be considered because the behavioural manifestations, as well as the underlying cognitive abilities, will continuously change over time. In young children, especially, dramatic changes in terms of their reading-related skills are to be expected within only a year or two (see section 3.2). This was evident in study II of the present thesis, where age differences of only two years seemed to produce marked differences, both in the skill of using and the reliance on the two main word decoding strategies.

Returning to the discussion of interventions, clearly, the multi-dimensional nature of reading disabilities suggests that there is no single, uniform "cure" for all types of reading disabilities (cf. McGuinness, 1998). The strong evidence of phonological deficits in developmental dyslexia and the positive effects of phonological interventions (see section 4.1) suggest that this type of training should be considered for many children. However, the results of study V show that a strictly phonological intervention is not appropriate for all reading disabled children. An examination of the relative reliance on the two main word decoding strategies may be essential in suggesting educational interventions for children with established reading disabilities. It should be noted here that the training program used in study V was strictly phonological and that children seem to benefit from educational activities explicitly linking sounds to letters (Bradley & Bryant, 1983; Cunningham, 1990; Hatcher et al., 1994). Still, it remains to be demonstrated that this positive effect applies to all reading disabled children.

The results of study IV and V show that children who receive special instruction for reading in Sweden as a group do not fit a narrow definition

of developmental dyslexia because they also perform below normal on semantic and explicit memory measures. These global deficits in children who receive special instruction in reading suggest that research on reading disabilities should not be restricted to developmental dyslexia. For example, it is not yet clear what effects a phonological intervention would have on dyslexics compared to garden-variety poor readers (note that the intervention studies referred to in section 4.1 were not specifically directed to developmental dyslexics). The reported positive effects of phonological interventions (e.g. Ball & Blachman, 1988; Lundberg et al., 1988; Torgesen et al., 1992) were constituted by average improvements that might reflect "hothouse effects" for children who were delayed in their reading development rather than improved reading skills in dyslexic children with more severe reading difficulties (Olson, Wise, Ring, & Johnson, 1997; Torgesen, Wagner, & Rashotte, 1997; Van der Leij, 1997).

7.2 Further research

The findings presented in the present thesis need to be replicated and examined in more detail in future studies dealing with varieties of reading disability. Another regression-based study, in which the subgrouping procedure is repeated using the same sample of reading disabled children, should be performed to examine the stability of the resulting subgroups over time. In comparison to study IV, this study should include more detailed measures of print exposure (i.e., questionnaire data in combination with more indirect measures of print exposure such as an author recognition test or a title recognition test). Such a study should also include several measures of phonological processing skill to facilitate a more detailed examination of the possible phonological deficits in the phonological type of reading disability.

In order to examine individual differences in the use of word decoding strategies in text reading, eye-movement tracking seems to be a promising online technique (Rayner, 1985b). Measures of eye-movements could perhaps be used in combination with measures of orthographic and phonological word decoding skills in the classification of subgroups.

A longitudinal intervention study, where subgroups are defined prior to interventions, should be valuable in the search for more effective training programs. This would be due to its better adaptation to the specific needs of different groups of reading disabled children. Several different interventions should be included in such a study and the differences in effect sizes between

subgroups should be focused in the analysis of the results. At least some of the methodological pitfalls identified by Troia (1999) should be avoided when designing such an intervention study (the experimentally ideal condition might be very hard to obtain in ordinary school settings). For example, better control of potentially confounding teacher effects should be achieved.

7.3 Conclusion

In final conclusion, it is clear that reading disabled children constitute a heterogeneous group. Also, the inclusion of IQ does not seem to offer an appropriate basis for the classification of reading disabilities. The present thesis demonstrates that the relative skill in using the phonological and the orthographic word decoding strategies may provide a useful basis for identifying subgroups of reading disabled children. It seems that the phonological type of reading disability is characterised by specific deficits in phonological processing. The surface type of reading disability seems to be characterised by more global deficits, suggesting a general developmental delay (possibly also associated with environmental factors). When designing educational interventions for reading disabled children it seems important to examine the relative reliance on phonological and orthographic word decoding in text reading. Thus, interventions should acknowledge what the child is already attempting to do when reading.

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Study I

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Intelligence and dyslexia: Implications for diagnosis and intervention

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Gustafson, S. & Samuelsson, S. (1999). Intelligence and dyslexia: Implications for diagnosis and intervention. *Scandinavian Journal of Psychology, 40,* 127–134.

In this paper we critically examine theoretical issues and practical consequences of including IQ in the definition of dyslexia. According to the discrepancy criterion individuals are classified as dyslexic if their reading skills are below what would be expected from their IQ scores. However, we argue that intelligence is a fuzzy concept and that there is no clear causal relationship between intelligence level and word decoding skills. Also, high and low IQ poor readers show the same reading performance patterns, indicating that both groups might benefit from the same remedial activities. Evidence for the critical role of phonological skills in dyslexia is presented and a more recent definition of dyslexia is discussed in relation to these findings. Finally, two alternative, more outcome-based classifications of poor readers are suggested and some critical consequences for individual interventions are outlined.

Key words: Intelligence, dyslexia, diagnosis, intervention.

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This paper is focused on the inclusion of IQ in the diagnosis of dyslexia and what implications this has for different categories of poor readers. The classification of poor readers might seem to be a rather theoretical issue, but it also has important practical consequences. For instance, if a child is labelled as dyslexic, this might influence what kind of intervention the child will receive.

First, we will discuss which poor readers are traditionally being categorised as (developmental) dyslexics in the research literature and in clinical settings together with some implications of this categorisation. In this section, we will focus on the discrepancy criterion and discuss the relevance of including the concept of intelligence in the definition of dyslexia. In the next section, we discuss a more recent definition of dyslexia in relation to earlier discrepancy-based definitions and findings concerning the critical role of phonological skills in dyslexia. Then follows a discussion of two alternative and more outcome-based categorisations of poor readers. Finally, we try to relate the more theoretical aspects of classifications to some practical considerations concerning the diagnosis and treatment of poor readers.

DYSLEXIA AND THE DISCREPANCY CRITERION

To put the concept of dyslexia in some perspective, we will briefly discuss the traditional definition of dyslexia and explain what the discrepancy criterion means. In 1968, The World Federation of Neurology formulated the perhaps most commonly used definition of developmental dyslexia:

"A disorder manifested by difficulty learning to read, despite conventional instruction, adequate intelligence and sociocultural opportunity. It is dependent upon fundamental cognitive disabilities which are frequently of constitutional origin".

This definition mainly consists of excluding criteria. That is, it tells what should not be classified as dyslexia, but does not include much information about the specific problems associated with dyslexia. The definition states that a dyslexic child has to be of adequate intelligence and this is also what is stated by proponents of the discrepancy criterion. This criterion is based on the extent of the discrepancy between a person's potential for reading and his or her actual reading ability. Typically, the reading *potential* is estimated by administering an intelligence test and then projecting the reading potential from the IQ score (Aaron, 1997). In order to be classified as dyslexic, the *actual* reading ability has to be below normal, IQ has to be at least normal and there has to be a discrepancy between actual reading ability and potential reading ability. There is, however, no general agreement on the extent of discrepancy that should be taken as a marker of dyslexia. This cut-off point varies over time and across school districts. According to Aaron (1997) it is a fiscal more than a psychological decision, that is, it is based on how much resources are being allocated to the school district. The discrepancy criterion is the conventional diagnostic procedure for identifying reading disability in the U.S. (Aaron, 1997) and it is also widely used in other countries. However, in recent years the discrepancy criterion has been criticised by several researchers (see Stanovich, 1996, for a review).

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PROBLEMS ASSOCIATED WITH THE DISCREPANCY CRITERION

The association between IQ and reading skills

The exclusion of poor readers with low IQ scores might at first seem to be a reasonable excluding criterion. It might seem natural that people of low intelligence should not be called dyslexics because they are more or less generally "retarded" and therefore it should come as no surprise that they are also impaired in reading and writing. However, as several authors have pointed out, the relationship between intelligence and reading is not clear at all.

Firstly, we would like to point out that *intelligence is a fuzzy concept in itself*. There are so many possible and equally plausible definitions of this term that we would argue that no one really knows what intelligence is (see Sternberg & Detterman, 1986; Sternberg, 1990, for a variety of conceptualisations). If this fuzzy concept is included in the definition of another fuzzy concept like dyslexia one is walking on thin ice, we think.

Secondly, Stanovich (1996), Høien and Lundberg (1992), and Aaron (1997) have pointed out that the *correlation between intelligence and decoding skills is not impressive*. Typically the correlation coefficients is reported to be in the range of 0.4–0.5 (Aaron, 1997). This means that only about 16% to 25% of the variance in decoding can be accounted for by IQ. Thus, people can be either good or poor at decoding words regardless of their IQ level. If there is not a high correlation between IQ and decoding, the relevance of the concept of intelligence for the definition of dyslexia certainly can be questioned. If the requirement is that the label dyslexia should be restricted only to those people who are normal in all other respects than their reading skills not many people would be left in this category, if any at all. How many of us "normals" would not fall below normal on at least one of all possible psychological, biological or sociocultural measures? IQ should only be included in the definition of dyslexia if there is a strong *causal* relationship between those two concepts. It is also important to note that the assumption, when using the discrepancy criterion, is that IQ determines reading ability *and not vice versa*. Correlational studies can never provide evidence for such a causal relationship. Evidence that there are secondary effects of reading disabilities which can lower the verbal IQ score of poor readers also indicate that there might be a causal relationship in the opposite direction (Sanovich, 1986; van den Bos, 1989). One well-documented and important secondary effect of reading disability is that poor readers spend less time in reading activities than good readers, and therefore, often fail to develop sufficient language and vocabulary skills (Aaron, 1997). Thus, even if intelligence is not directly impaired, reading disability might lower the performance on an IQ test because of secondary effects. To exclude a poor reader from the dyslexic group because of a low IQ score which was partly caused by the reading disability in itself cannot be regarded as a logically valid operation.

Groups excluded because of the discrepancy criterion

One serious drawback with the conventional definition based on a discrepancy between intelligence and reading skills is that it excludes two groups who in fact have deficits in word decoding and who show a discrepancy between actual and potential reading ability. In order to be classified as a dyslexic according to the discrepancy criterion one has to perform below normal on reading measures (i.e., standardised measures of reading ability and reading comprehension). This leaves out those who are successful at compensating for deficits in word decoding, for instance by making use of contextual cues when reading (Høien & Lundberg, 1992; Snowling & Nation, 1997). In fact, recent studies indicate that dyslexics benefit more from context than normal readers (Snowling & Nation, 1997). Snowling and Nation (1997, p. 162) suggest that this provides an explanation for how "many dyslexic children eventually attain reasonable levels of word-reading accuracy, despite persisting difficulties with phonological processing and nonword reading". The point we want to make here is that once a dyslexic child learns to compensate, the child would cease to be dyslexic according to the discrepancy criterion. It is not clear that individuals who have phonological deficits, which lead to relatively poor word decoding skills should be excluded from the dyslexic population if they are able to compensate for these difficulties on some reading measures. If the underlying cause of their relatively impaired word decoding skills is identical to that of dyslexics, they would also be expected to benefit from the same training as dyslexics (e.g., phonological training). It should also be noted that reading skill is a continuous variable. Thus, the reading skills among normal readers vary considerably and a move from the lower end of the normal reading continuum to the higher end of that continuum might represent a statistically and personally significant improvement. The underlying problem here seems to be that the discrepancy criterion does not really acknowledge the cause of the difficulties (presumably phonological deficits, see below), or how these difficulties are manifested (poor decoding skills).

Also, and perhaps more importantly, there is a group of people who perform below normal on tests of reading skill but who are not being classified as reading disabled or dyslexics. Those are the poor readers who perform below normal both on measures of reading ability and measures of intelligence. The fuzziness of the concept of intelligence has already been mentioned, but even if one accepts the validity of IQ scores, the exclusion of poor readers with low intelligence is not by any means self-evident. Several researchers argue that it should be possible to have dyslexia even if the IQ score is below normal (Høien & Lundberg, 1992; Siegel, 1988; Stanovich, 1996; Tønnessen, 1997). One argument is again that there is not a high correlation between intelligence and word decoding skills. Thus, the

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population of children who are poor at word decoding should represent almost the same range of intelligence as normal readers. Another problem is that there are several confounding factors which may decrease the IQ score so that the discrepancy disappears. In a recent study, Siegel and Himel (1998) have demonstrated that the measured IQ score of a dyslexic child decreases with age, leading to a reclassification from dyslexic to poor reader if the discrepancy criterion is used (cf. Stanovich, 1986). If dyslexic children also learn to compensate by making more use of context with increasing age (Snowling & Nation, 1997) this reclassification will be reinforced. Siegel and Himel (1998) also showed that IQ scores of children are negatively affected by a lower socioeconomic status of their parents and as a result, children from lower socioeconomic backgrounds will tend to be excluded from the dyslexic category, and vice versa. Our own research on very low birth weight children (i.e., less than 1500 g) suggests that differences in intellectual abilities are more pronounced than differences in reading skills (i.e., both reading comprehension and word decoding skills) when very low birth children are compared with full-term normal weight children. Consequently, very low birth weight children with reading difficulties were less frequently classified as dyslexics by the discrepancy criterion (Samuelsson *et al.*, 1998).

Thus, if the exclusion from the dyslexic category is solely based on the discrepancy between IQ and reading ability this has serious consequences for several, quite different groups of poor readers. If one accepts that the cause of dyslexia has nothing to do with factors such as socioeconomic status, age, or birth weight, these factors should not determine who is classified as a dyslexic and who is not (cf. Tønnessen, 1997).

Finally, it should be pointed out that children who are poor readers and have low IQ scores also are in need of remediation focused on their reading difficulties. It is important not to exclude a group of children from the dyslexic population and then forget about them. The key question here is how specific the impairment has to be in order for a child to be classified as a dyslexic. It is possible to have two problems at the same time and still be dyslexic? If not, what happens to the children who are excluded by the definition (often referred to as "garden variety" poor readers)?

The discrepancy criterion might do more harm than good because the two groups of poor readers described above are excluded from the dyslexic population. The high IQ group is probably regarded as representing normal readers even if this group also might benefit a great deal from training. As for the low IQ group, its potential for improved reading ability can be expected to be generally underestimated. This group might be regarded as "generally retarded" and might not receive any training specifically focused on their word decoding difficulties, even if this could turn out very well. The case of hyperlexia should be mentioned in relation to this. There is evidence that in some cases people with very low IQ scores, who are in fact severely retarded in most other aspects, still can learn to master the technical aspects of reading (i.e., word decoding). In fact, reading can be a passion for these subjects, labelled hyperlexics (Aarson, 1989). Thus, it does not follow that if you perform below normal on an IQ test you should also be poor at word decoding.

The discrepancy criterion and dyslexia among adults

So far, we have presented groups of readers that are excluded from the dyslexic category by the discrepancy criterion. Now we turn to a specific discussion of the effects of the discrepancy criterion on the diagnosis of dyslexia in adults. When assessing reading skills and intelligence level in adults, there is an important confounding variable that has to be taken into account, namely experience with written language (Stanovich & West, 1989). Neglecting this variable leads to a risk that individuals with very little contact with written language and therefore having insufficient reading skills will be included in the dyslexic category, not on the bais of any cognitive deficits but rather because of educationally or socially deprived backgrounds. It can be assumed that, at least non-verbal (performance), IQ would be less affected by limited exposure to written language than the reading skills of the individual. Thus, if the cause of the reading difficulties is ignored in the definition and the categorisation is soley based on the discrepancy between intelligence and reading skills there is a risk of including individuals with poor reading capabilities caused by experiential rather than constitutional factors (Vellutino *et al.*, 1997). Consequently, one would expect to find an increased prevalence of dyslexia among adults whose social and educational conditions have been poor. Studies reporting very high prevalences of dyslexia among prison inmates and juvenile delinquents suffer from dissemination from these confounding variables (Samuelsson *et al.*, 1998). For instance, in a study of prison inmates, Alm and Andersson (1995) concluded that 19 out of 61 inmates (31%) were dyslexic. An even higher prevalence were reported in Jensen *et al.* (1997), who diagnosed 26 out of 63 prison inmates (41%) as dyslexic and an additional 6 subjects (10%) as borderline cases. Studies of juvenile delinquents have reported a prevalence of dyslexia ranging between 50 to 85% in their samples (Dalteg & Levander, in press; Underwood, 1976). However, in none of these studies have the phonological decoding skills of the subjects been compared to the skills of a relevant control group (i.e., a group matched on reading level). Thus, these studies cannot really conclude whether the reading difficulties found in their "dyslexic" subjects are caused by phonological deficits, which are assumed to be at the core of dyslexia (see next section in this paper), or if those reading difficulties are merely a consequence of the subjects' lack of experience with written language.

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The discrepancy criterion and remediation

One argument from the defenders of the discrepancy criterion might be that children of different levels of intelligence benefit from different training methods. If this is the case, a categorisation of poor readers based on intelligence could be justified by the positive educational implications. In order for the inclusion of IQ in the definition of dyslexia to be motivated, different levels of intelligence should be associated with different patterns of reading difficulties. However, empirical support is lacking for this argument. On the contrary, several studies have shown that poor readers with high and low IQs do not differ on indicators of reading difficulties such as phonological processing (Ellis *et al.*, 1996; Felton & Wood, 1992; Fletcher *et al.*, 1994; Fredman & Stevenson, 1988; Hurford *et al.*, 1994; Siegel, 1988, 1992; Stanovich & Siegel, 1994) and orthographic processing (Fredman & Stevenson, 1988; Siegel, 1992; Stanovich & Siegel, 1994). Furthermore, poor readers with high and low IQs show very similar growth curves for reading development (Francis *et al.*, 1996). Stanovich (1996, p. 159) concludes that "there is now substantial evidence indicating that the nature of processing within the word recognition module is quite similar for poor readers of high and low IQ". Of course, poor readers with high and low IQ should differ on operations related to the tasks included in the particular intelligence test administered. The point here is that they do not differ on the most critical tasks, that is, tasks more directly related to reading. Thus, if IQ scores are used to create subgroups of poor readers, the resulting subgroups will be very similar with respect to different reading skills and the subgrouping would only have limited value for suggesting appropriate interventions. As a matter of fact, according to Aaron (1997) the most serious drawback with the discrepancy criterion might be that it is not outcome-based, that is, it gives no hint on what is the cause of the reading problems of a poor reader, nor does it suggest any particular intervention.

To summarise, there are serious drawbacks with the discrepancy criterion. First of all, the concept of intelligence is fuzzy in itself. Second, evidence that IQ is causally related to reading skills is lacking. Third, if the cause of the reading difficulties is ignored in the definition, two groups of people who might have the same underlying deficits as the dyslexic individuals, are excluded from the dyslexic category, whereas other poor readers might be regarded as dyslexic without justification. Finally, the discrepancy criterion does not seem to be useful for pedagogical purposes, that is, in designing training programs for poor readers.

THE ROLE OF PHONOLOGICAL SKILLS IN DYSLEXIA AND A MORE RECENT DEFINITION

In order for an intervention to be successful it should be aimed at the cause of the experienced problems. Today, there is very strong evidence that phonological skills are critical in learning how to read (see Share & Stanovich, 1995, for a review). Numerous studies have shown that dyslexic children, who perform poorly on measures of reading skills, also perform below normal on different phonological tasks (Lundberg & Høien, 1989; Rack *et al.*, 1992; Snowling, 1981; Snowling & Hulme, 1989; Stanovich, 1988). It has also been demonstrated that phonological awareness measured before formal reading instruction in school has been initiated, is a good predictor of later reading achievement in the first grades in school (see Goswami & Bryant, 1990; Wagner & Torgesen, 1987, for reviews). Evidence for a causal relationship between phonemic or phonological awareness and reading skills comes from several longitudinal intervention studies (Ball & Blachman, 1988, 1991; Bradley & Bryant, 1983; Hatcher *et al.*, 1994; Lie, 1991; Lundberg *et al.*, 1988; Torgesen *et al.*, 1992). All these studies demonstrate that children who receive systematic training in phonological (or phonemic) awareness (e.g., rhyming, position analysis, segmentation, and blending) improve their reading skills more than control groups receiving other types of training.

These findings have to some extent been incorporated in recent definitions of dyslexia. The Orton Dyslexia Society Research Committee in 1994 suggested the following working definition:

"Dyslexia is one of several distinct learning disabilities. It is a specific language-based disorder of constitutional origin characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalised developmental disability or sensory impairment. Dyslexia is manifest by variable difficulty with different forms of language, often including, in addition to problems with reading, a conspicuous problem with acquiring proficiency in writing and spelling" (see Lyon, 1995).

This definition is more inclusionary than that of the World Federation of Neurology from 1968, previously presented in this paper. The more recent definition states that dyslexia is characterised by difficulties with single word decoding and that these problems are usually caused by insufficient phonological processing skills. However, it can be argued that, at least to some extent, the definition still incorporates the idea of a discrepancy because it is stated that the difficulties in word decoding often are "*unexpected in relation to age and other cognitive and academic abilities*". One critical question that can be asked regarding this definition is whether it is possible to perform below normal on other cognitive and academic measures and still be classified as dyslexic. The definition does not acknowledge that even if dyslexia in itself is a specific deficit, which mainly affects the word decoding skills of the individual, there are potential secondary effects of dyslexia which could affect other cognitive and academic measures

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(Stanovich, 1986). For instance, some dyslexic children might tend to avoid written language possibly leading to a generally weaker academic performance.

According to Tønnessen (1997), statements such as "unexpected underachievement", which are often found in articles based on discrepancy definitions of dyslexia, are unfortunate because often it is only our lack of knowledge which makes a weak performance unexpected. Stanovich (1996, p. 156) thus argues that "The reading failure of a high IQ individual *is* expected if the person is low in phonological awareness. It is really only ignorance of current models of reading failure and of theories of intelligence that leads a layperson to consider reading failure in a high IQ individual 'unexpected'". Consistent with this argument, in young children, phonological awareness is a better predictor of their subsequent reading development than is intelligence (see Stanovich, 1992, for a review).

Also, it is not clear which individuals would be excluded because of "generalized developmental disability". Again, one could ask how specific the difficulties have to be in order for the child to be classified as dyslexic. Thus, even if this definition does not explicitly state that there must be a discrepancy between intelligence and reading skills in order for an individual to be dyslexic, the definition still leaves some room open for interpretations based on this way of thinking.

MORE OUTCOME-BASED CATEGORISATIONS OF POOR READERS

Many problems with the discrepancy criterion probably derive their origin from the fact that intelligence is a very broad concept, covering a wide range of cognitive abilities. It is clear that there are important higher level functionings, such as semantic processing, involved in reading as well as lower level processes, such as word decoding. Perhaps one should look at the aspects of higher level functioning or intelligence which are *most relevant* with regard to the process of reading. Gough and colleagues (Gough & Tunmer, 1986; Hoover & Gough, 1990) have outlined a simple view of reading that consists of two components; one lower level process, word decoding, and one higher level process, comprehension. Aaron (1997) argues that the distinction between these two components can help in the diagnosis and treatment of reading disabilities. Aaron (1997) identifies three subgroups of poor readers; one group with an impaired word decoding but intact understanding (developmental dyslexia or specific reading disability), another group with an impaired understanding but intact word decoding (non-specific reading disability), and a third group in which both word decoding and understanding is impaired (generalised reading disability). Aaron (1997) has identified symptoms associated with each of these subgroups of poor readers and has also suggested different treatment procedures for the three groups. In short, the training should be aimed at either improving the word decoding skills (by phonological training) or by improving comprehension skills (by vocabulary instruction, development of background knowledge and schemata, and strategy instruction) or both, depending on what constitutes the problem of a particular child (Aaron, 1997).

In recent years, phonological training has become a popular method for training poor readers. However, phonological training should not be adequate for children who have no difficulties in decoding, but do have difficulties understanding what they read (Aaron, 1997). Here, it is important to remember that even if these children are not regarded as dyslexics at school by their special education teachers, there is a risk that the special education teachers might generalise the effectiveness of phonological awareness training for dyslexics to another group of poor readers (i.e., poor comprehenders). Remember that the pedagogical work with children is often carried out with groups of children. Thus, it might be impossible for a special education teacher to provide tailor-made training for each and every child.

At least in Sweden, not so many children have been formally diagnosed as dyslexics. Our impression from contacts with special education teachers is that they often have personal opinions on what constitutes the main problem of a particular child, but there is also often a feeling of uncertainty. This is perfectly natural since a formal diagnosis of dyslexia requires that people from different professions (medical doctors, opticians, speech therapists and psychologists) examine the child carefully, normally during several days. We think that the limited resources which lead to teachers spending less time with the children individually and the uncertainty concerning the nature and cause of the reading difficulties might lead to a search for universal solutions. Perhaps there is a risk that phonological training will be over-used pedagogically in the future, especially since the status of the term dyslexia seems to improve continuously, while there is no generally accepted term for children who have normal word decoding skills but an impaired understanding of written texts. These children should not benefit from training designed for dyslexic children because their main problem is not phonological or orthographical word decoding deficits, but the more semantic aspects of the written language. On the other hand, children who are poor comprehenders and also poor at word decoding could very well benefit from training designed for dyslexic children.

Our own research also suggests that it is important to keep an individual difference perspective when designing training programs for poor readers. In our study (Gustafson *et al.*, 1997; Samuelsson *et al.*, 1997), IQ scores were not used to divide poor readers into subtypes. Instead, we looked at what characterized those poor readers (named Improved readers) who benefited the most from a phonological intervention and those poor readers who did not

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benefit from the same intervention (Resistant readers). In short, we found that what differed between the two groups was that the Improved readers relied, at least to some extent, on the phonological reading strategy, in which letters are translated into their corresponding sounds, whereas the Resistant readers seemed to rely only on a visual, orthographic strategy for word decoding. Our study, thus, suggests that it might be important to examine which word decoding strategy a particular child is normally using when he or she is reading, before planning and implementing a training program. The way a child is actually reading is much more directly related to the reading difficulties of that particular child than the problematic concept of "intelligence". Also, it should be much easier to find out the extent to which a child is using the two main reading strategies (the phonological and the orthographic) than to administer a complete standard test of intelligence with its numerous sub-tests. More importantly, it should be more helpful in designing relevant training programs for poor readers.

CONCLUDING REMARKS

To summarise, the concept of intelligence is problematic in itself and becomes even more problematic when it is combined with the concepts of reading difficulties and dyslexia. Instead of using the broad concept of intelligence one could use the model proposed by Hoover and Gough (1990) and Aaron (1997) in which poor readers are classified according to the two components comprehension and word decoding skills. Comprehension is more directly related to reading than is intelligence and an assessment of comprehension is more outcome based since it gives more hints on what could be an appropriate intervention. Or perhaps one should study the way that the child is reading even more directly by examining the reliance on the two main word decoding strategies. By doing this, one also brings the more developmental aspects of reading into focus, as the relative reliance on the two strategies for word decoding is assumed to change with age from a more phonological to a more orthographic reliance in word identification (Ehri, 1987; Juel *et al.*, 1986; Samuelsson *et al.*, 1996). By studying the reliance on the word decoding strategies one might be able to assess if the child is using the orthographic strategy before being able to actually use it successfully (perhaps due to phonological deficits as in "phonological dyslexia"), or if the child is "stuck" in an early phase of the reading development process and has failed to advance from a more phonological to a more orthographic word decoding strategy.

It is crucial to recognise the importance of the "labels" put on a poor reader. The reading disability termed dyslexia is receiving much attention now, but what happens to children who are excluded from this group? What kind of training do poor comprehenders receive in school today, for instance? Clearly, there is a need for more research concerning the different types of reading disabilities, both research aimed at examining the reading difficulties themselves, since this can assist in suggesting relevant interventions, as well as more socially oriented research. It should be important to examine what and who determines what diagnosis, if any, different poor readers receive and what effects different diagnoses have on how the children are being treated by their environment. It would also be interesting to examine empirically what effects formal or informal assessments of intelligence have on the treatment of poor readers.

To conclude, we argue that instead of assessing IQ when diagnosing poor readers, it should be more theoretically valid, and better for educational purposes as well, to examine the critical manifestations and causes of the reading difficulties. In the case of dyslexia, we would suggest that phonological skills and word decoding skills should be the focus of the examination. Furthermore, if one believes that it is useful to distinguish between difficulties in text reading caused by lower level and higher level processes, respectively, comprehension tests should be preferred before standard tests of IQ, because comprehension is a function more directly related to reading than is the very broad concept of intelligence. It should also be useful to examine the relative reliance on the orthographic and the phonological word decoding strategy because this should have implications for what could be an appropriate intervention. We do believe that it is important to acknowledge individual differences, within any group of poor readers, before and during an intervention.

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Study II

The Development of Word-decoding Skills in Young Readers

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ABSTRACT *Most of the research on the acquisition of word-decoding skills has almost exclusively focused on the ability to read words in isolation. The purpose of this article is to extend our knowledge to the independent role of phonological and orthographic word-decoding skills in the reading tasks which children encounter in school. The data were quite consistent with the general core of models suggesting that children first become proficient in phonological decoding then gradually shift towards a more direct orthographic-decoding strategy. As such, these findings have helped to generalize models of the acquisition of word-decoding skills to reading comprehension.*

INTRODUCTION

Models of the acquisition of word-decoding skills usually describe two major stages of growth in becoming a proficient reader (Seymoor & MacGregor, 1984; Frith, 1985; Baron, 1986; Ehri, 1987; Høien & Lundberg, 1988, 1989, 1992).

The first process, phonological decoding in word recognition, can be defined as the ability to transform letters into sounds prior to the identification of meaning. The empirical picture of phonological decoding is quite clear that phonology is: (i) critical for early reading acquisition, and (ii) the main problem that characterizes developmental dyslexia (see Share & Stanovich, 1995, for a review). This means that skill in early word-decoding is supposed to be mainly based on print-to-sound translation—in which word meaning is accessible primarily via an extensive oral vocabulary—and that this phonological route to specific lexical destinations is disrupted in dyslexic children. Moreover, it is even suggested that phonological-processing abilities may be causally related to the normal acquisition of a beginning reading skill (Bradley & Bryant, 1985; Wagner & Torgesen, 1987; Lundberg *et al.*, 1988).

The second process, orthographic decoding in word recognition, can be defined as the ability to represent word-specific visual features, and the storage of these orthographic representations in memory. That is, the second stage in the acquisition of word-decoding skills can also be described as the growing of a body of detailed

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orthographic knowledge which is seen as necessary in becoming fast and efficient at word decoding (Barker *et al.*, 1992). The development of word-specific orthographic representations is also assumed to be critical for the achievement of proficient spelling. This means that phonological- and orthographic-decoding skills should not be seen as two independent components in reading development, but rather there is an early reliance on phonological decoding and then a gradual shift toward a more direct orthographic-decoding strategy (Frith, 1985; Høien & Lundberg, 1988, 1989). This gradual shift in word-decoding strategies suggests that skill in phonological processing is important for the development of orthographic representations, and that there is usually a rather strong correlation between tasks measuring phonological and orthographic skills (Juel *et al.*, 1986; Lundberg & Høien, 1990). Thus, as a general conclusion, most models of the acquisition of word-decoding skills suggest that children at different reading levels rely on different types of decoding strategies in recognizing words, and that beginners show a strong reliance on phonological decoding, whereas more experienced readers should rely more on orthographic decoding.

As can be inferred from the foregoing discussion, skill in phonological processing is assumed to play an important role in the acquisition of word-decoding skills in young readers, and readers gradually move into the orthographic stage of word decoding as they become more efficient at using the phonological approach to identify printed words. According to this view of the acquisition of word-decoding skills, it has also been demonstrated in several intervention studies that young children indeed improve their early-word decoding skills after receiving structural phonological training (Bradley & Bryant, 1983; Lundberg *et al.*, 1988; Cunningham, 1990). This early improvement in word-decoding skills is also paralleled by an increase in phonological-processing skills. However, it is less certain that an increase in phonemic skills and early word-decoding skills is generalizable to reading comprehension, that is, not only to the ability to identify single words, but to read and comprehend a coherent text. The fact is that the vast majority of studies focusing on the relation between phonological processing and reading ability have almost exclusively used (different) tasks that measure the ability to read words in isolation, and thus there are few studies which focus on the extent to which different word-decoding strategies contribute to text reading (Barker *et al.*, 1992). This means that there is plenty of empirical support for a strong relation between phonological skills and early word decoding and that different programmes to teach phonological skills indeed increase both phonological awareness and word-decoding skills in young readers, but there are only a few studies which focus on the relation between word-decoding strategies and reading tasks which resemble the type of reading experience that children actually encounter in school.

Therefore, the purpose in this article is to extend our knowledge of the independent role of phonological and orthographic word-decoding skills in reading comprehension. This question is further explored by examining how different levels of both phonological and orthographic word-decoding skills interact with reading comprehension.

METHOD

Participants

Sixty 8-year-old children (29 boys and 31 girls), and sixty 10-year olds (36 boys and 24 girls) participated in the study; they were selected from 10 different schools in Norrköping, Sweden. The children were tested at the beginning of their second and fourth school year, and thus the 8-year-old children had been receiving reading instruction for about one year, and the 10-year-olds for about three years. In the remainder of this article, these two age groups will be referred to as novice readers and experienced readers. Interviews with the teachers of the participating schools revealed that their initial reading instruction mainly stressed phonological training, such as linking sounds and letters together. Typically, whole-word training was given later in their formal instruction in reading. All the children in the study were highly fluent in the Swedish language.

Materials and Procedure

The children were tested in their classrooms and the number of children in each test session varied between 7 and 13. First, they were instructed to read two pronounceable non-words at a time: their task was to decide as quickly and accurately as possible which non-word sounded like a real word in Swedish (for example, *tjyrka* versus *kyrla*; a phonological word-decoding test). There were 120 non-word pairs in the test, with 20 pairs on each page. The children were allowed to work with the test for only 2 minutes. Since non-words are visually unfamiliar to the children, they cannot be identified orthographically, and thus, the children have to use a phonological-decoding strategy. The number of correctly identified non-words, minus errors, was taken as a measure of phonological word-decoding skill.

After the phonological-decoding task, the children were, once again, instructed to read word pairs and to identify as quickly and accurately as possible the word which was correctly spelled (orthographic word-decoding test). In this test, the phonological codes for the two words are identical, that is, both words would be pronounced identically as a real word in Swedish (for example, *taksi* versus *taxi*). This means that the children have to rely on their memory for specific orthographic patterns to make a correct response. The number of word pairs and the time limit were the same as for the phonological-decoding test, and, finally, the number of correctly identified words, minus errors, was taken as a measure of orthographic word-decoding skill.

Following the phonological and orthographic word-decoding tests, the children participated in two reading-comprehension tests (Malmquist, 1977). In the first reading test, the children received a short story (600 words in length) about two animals stealing fruits from a gardener. Furthermore, 20 sentences in the text were incomplete, that is, one word was missing and replaced by three single words presented within parentheses. The children were asked to read the story as quickly and accurately as possible and to select one of the three possible words to complete the sentences in an appropriate way. The children were allowed to work with the test

TABLE I. Mean performance of word-decoding skills and reading comprehension for novice and experienced readers, and the standard deviations (SD) of the distributions

	Word-decoding task					
	Phonological		Orthographic		Reading comprehension	
Reading-skill groups	*M*	SD	*M*	SD	*M*	SD
Novice readers	14.4	7.8	8.6	8.5	23.4	12.7
Experienced readers	20.4	8.9	25.9	12.9	38.7	8.7

for 6 minutes. In the second reading test, the children were instructed to read 12 short stories (the length of each story varied between 20 and 150 words) as quickly and accurately as possible and to answer multiple-choice questions on each story. There was a total number of 33 multiple-choice questions, and the children were allowed 8 minutes to complete the test. The total number of correct responses from both reading tests (that is, 20 plus 33 correct responses) was then used as an index of reading performance.

RESULTS AND COMMENTS

As a first step in the data analysis, we wanted to verify the differences between novice and experienced readers in word-decoding skills and reading comprehension. As can be seen from Table I, there are significant differences between novice and experienced readers in phonological skills, $t(118) = 3.89$, $p < 0.01$, and orthographic skills, $t(118) = 8.68$, $p < 0.0001$, as well as in reading comprehension $t(118) = 37.65$, $p < 0.0001$. Thus, these results indicate that our groups of novice and experienced readers represent two distinct levels in reading skill.

To examine the relative contribution of phonological and orthographic word-decoding skills to account for reading comprehension, we performed two separate multiple-regression analyses, one for each level of reading skill. These analyses revealed strong multiple correlations between phonological and orthographic word-decoding skills and reading comprehension for both the novice readers ($R = 0.79$, $p < 0.0001$), and the experienced readers ($R = 0.67$, $p < 0.0001$). This means that phonological- and orthographic-decoding skills together account for 62% and 45% of the variance in reading comprehension for novice and experienced readers, respectively. Furthermore, a closer look at the contribution of each decoding skill separately revealed that orthographic word-decoding skill was a significant predictor for both novice and experienced readers ($\beta = 0.50$, $p < 0.0001$ and $\beta = 0.58$, $p < 0.0001$, respectively), whereas phonological word decoding was only significant when predicting reading comprehension for novice readers ($\beta = 0.37$, $p < 0.001$). These results indicate that both phonological and orthographic word-decoding skills made strong contributions to the reading performance of novice readers, whereas orthographic-decoding skill was only associated with reading comprehension in experienced readers.

The next question addressed here is whether different levels of word-decoding

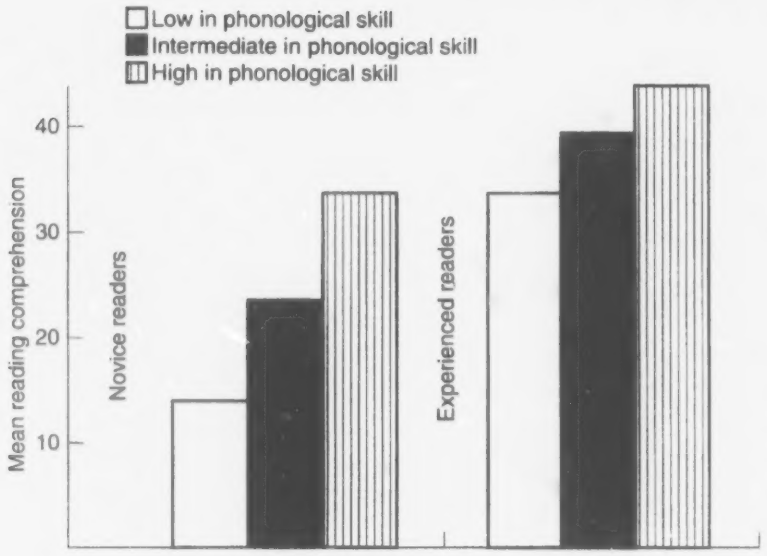

FIG 1. Reading comprehension as a function of three levels of phonological skills in novice and experienced readers.

skills interact with reading performance; that is, in what way does an increase in either phonological or orthographic word-decoding skill promote development in reading performance. To do this, we divide the group of novice readers into three levels of phonological and orthographic skills, that is, 20 novice readers with high phonological- and orthographic-decoding skills, 20 novice readers with intermediate skills and, finally, 20 with low skills. Exactly the same procedure was employed for the group of experienced readers. The mean differences between each level of both phonological- and orthographic-decoding skills were significant for both reading groups ($ps < 0.05$).

Results for mean reading comprehension as a function of phonological and orthographic word-decoding skills and reading group are shown in Figs 1 and 2, respectively. A 2×3 (levels of phonological-decoding skill by reading skill) analysis of variance (ANOVA) on their reading comprehension yielded a significant interaction, $F(2,114) = 3.13$, $p < 0.05$, $MS_e = 84.03$, suggesting that the difference in reading comprehension for novice readers as a function of phonological skill is much more pronounced than in more experienced young readers. The corresponding analysis for different levels of orthographic skills also revealed a significant interaction, $F(2,114) = 4.11$, $p < 0.05$, $MS_e = 66.82$. This effect suggests that the differences between novice and experienced readers are much larger for groups with intermediate and poor orthographic word-decoding skills than for children with good orthographic skills.

These results are consistent with the general core of models suggesting that children show an early reliance on phonological decoding together with a gradual shift toward a more direct orthographic-decoding strategy in their first steps in becoming proficient readers. This interpretation is also illustrated by a more pro-

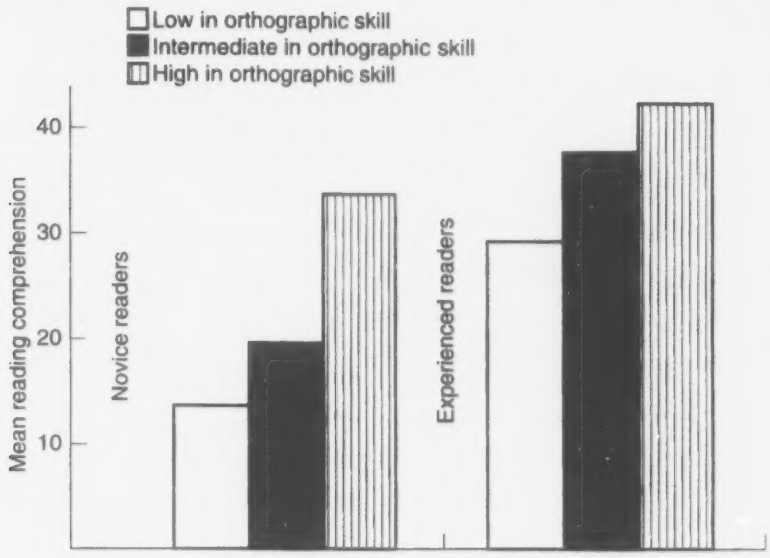

FIG 2. Reading comprehension as a function of three levels of orthographic skills in novice and experienced readers.

nounced correlation between phonological- and orthographic-decoding skills in novice readers ($r = 0.70$, $p < 0.0001$) than in experienced readers ($r = 0.38$, $p < 0.01$).

However, our prediction that reading comprehension in novice readers should only be predicted by their phonological skills was not fully confirmed. Instead, both of the word-decoding skills contribute to the same extent to reading performance in novice readers. The most natural way of explaining this finding is to suggest that our novice chidren have moved beyond the very first stages in their development of word-decoding skills, and thus they might have adopted orthographic skills which complement their phonological strategy. To test this explanation, we performed a new regression analysis on half of the children in the group of novice readers whose reading comprehension was below the median ($n = 30$). This analysis, once again, revealed a significant multiple correlation ($R = 0.56$, $p < 0.01$), but orthographic-decoding skill was no longer a significant predictor of their reading comprehension ($\beta = 0.19$, $p > 0.05$). Instead, the phonological-decoding skill was now accounting for more than twice as much variance in their reading comprehension ($\beta = 0.44$, $p < 0.05$).

GENERAL COMMENTS

Most of the research on the development of reading skills has had its main focus on word-identification skills, and the general empirical picture is that both phonological and orthographic processing are involved in the identification of words in printed forms. Moreover, most models of the acquisition of word-decoding skills suggest that the relative influence of each decoding skill in word recognition gradually

changes with age in normal readers from a phonological to a more orthographic reliance in word identification. The findings in this article have helped to generalize models of word-decoding acquisition to reading comprehension.

The data reported in this study quite clearly shows that reading comprehension in children with only one year of reading experience (referred to as novice readers) was predicted by their skills in both phonological and orthographic word decoding, whereas the reading comprehension of children with three years of reading experience (experienced readers) was only predicted by their orthographic word-decoding skill. This general conclusion was also reinforced by the interactions between reading skill and levels of word-decoding skills, indicating an increase of the differences in reading comprehension between novice and experienced readers, with a gradual decrease in both phonological and orthographic processing.

These results are also encouraging with respect to the potential effect of using a phonological approach for young school children in their early reading acquisition. So far, intervention studies have almost exclusively included kindergarten children who have received phonological training before they have entered any formal reading instruction. The general empirical pattern from these studies is that children involved in different kinds of phonological activities perform better than age-matched controls in both early word-decoding skills and spelling. It should, however, be noted that the phonological approach to improving reading acquisition in very young children is shown to be less effective when generalized to later achievements in text reading. The present study suggests that phonological training should be considered even for children with one or two years of formal reading instruction in school, especially for those children performing below normal. It might even be possible that phonological training at this age could improve reading comprehension. A definite conclusion on this point will have to await an explicit intervention study.

NOTE

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Study III

Visual and Auditory Priming in Swedish Poor Readers: a Double Dissociation

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Schacter *et al.* (1990) found support for a functional dissociation between visual and auditory priming effects in a letter-by-letter reader. Their conclusions were based on the perceptual representation systems framework, suggesting that visual priming is mediated by a visual word form system separate from an auditory word form system responsible for auditory priming. This article focuses on visual and auditory priming effects exhibited by poor readers with phonological or surface subtypes of reading disability. The phonological type of reading disability was defined as an impairment in phonological word decoding, whereas the surface type of reading disability was defined as an impairment in orthographic word decoding. The results demonstrated a double dissociation, such that poor readers with a surface type of reading disability produced more auditory than visual priming, whereas poor readers with a phonological type of reading disability showed more visual than auditory priming. The majority of children with reading disabilities showed weaknesses in both orthographic and phonological word decoding and, importantly, low levels of priming effects for both visually and auditorily presented materials. Finally, age-matched normal readers showed significant priming effects for both visual and auditory presented words. These findings support the assumption that both orthographic and phonological skills can be simultaneously impaired and that a dual-route model for the acquisition of word decoding skills might be the most appropriate framework to describe different subtypes of reading disabilities. © 1998 John Wiley & Sons, Ltd.

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Keywords: poor readers; subtypes of reading disabilities; auditory and visual priming; dissociations

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Most models of the acquisition of word identification skills suggest that both phonological and orthographic information are involved in word decoding (Frith, 1985; Ehri, 1987; Ehri and Wilce, 1987; Seidenberg and McClelland, 1989; Castles and Coltheart, 1993; Colheart *et al.*, 1993; Manis *et al.*, 1996). Furthermore, most of the time an impairment in phonological word decoding excludes skill in orthographic word decoding, whereas skilled phonological word decoding is frequently associated with skilled orthographic decoding (Jorm and Share, 1983; Juel, Griffith and Gough, 1986; Freebody and Byrne, 1988; Lundberg and Høien, 1990; Gough and Walsh, 1991; Aaron, Wleklinski and Wills, 1993). It is, however, possible to dissociate among children whose phonological word decoding skills are much better than their orthographic decoding skills and vice versa (Seymour and MacGregor, 1984; Seymore, 1986; Stanovich and West, 1989; Rack, Snowling and Olson, 1992; Castles and Coltheart, 1993; Manis *et al.*, 1996; Stanovich, Siegel and Gottardo, 1997). An impairment in phonological processing relative to orthographic skills is commonly labelled developmental phonological dyslexia, and an impairment in orthographic processing relative to phonological skills is denoted developmental surface dyslexia (Coltheart *et al.*, 1983; Seymour and MacGregor, 1984; Campbell and Butterworth, 1985; Castles and Colheart, 1993; Manis *et al.*, 1996).

While there is some consensus that there are developmental forms of phonological and surface dyslexia, there is controversy about how to account for dissociations between orthographic and phonological weaknesses (Castles and Coltheart, 1993; Coltheart *et al.*, 1993; Manis *et al.*, 1996; Stanovich, Siegel and Gottardo, 1997). In the dual-route model of reading it is assumed that skilled readers have two routes available for word decoding and that there is, at least partially, an independence between these two routes (Castles and Coltheart, 1993; Coltheart *et al.*, 1993). The first route is called the lexical route, involving word-specific representations and the ability to read exception words. The second route is called the sublexical route and refers to the use of grapheme–phoneme conversion rules and the ability to read non-words. Within this approach, orthographic and phonological weaknesses in word decoding are related to a selective difficulty in using and/or acquiring either the lexical or the sublexical route for decoding.

The parallel distributed processing model proposes a single mechanism available for word decoding (Seidenberg and McClelland, 1989; Manis *et al.*, 1996). This mechanism is assumed gradually to acquire orthographic–phonological correspondences and sets of orthographic and phonological units are linked with weights which are determined by exposure to printed words and the consistency between spelling and sound (Seidenberg and McClelland, 1989; Manis *et al.*, 1996). This account suggests that an impairment in reading of non-words relative to exception words is caused by phonological weaknesses affecting normal functioning in the use of orthography to phonology conversions. A surface profile of reading disorders, on the other hand, is accounted for by suggesting a general delay in learning how orthography maps phonology (Manis *et al.*, 1996).

Thus, both models clearly suggest that the underlying deficit in a phonological subtype of reading disability is associated with problems concerning spelling–sound conversion. However, to further explore the relative strength in the assumptions made in each model, there are at least two questions that need to be evaluated. First, is it possible to provide independent evidence that orthographic and phonological decoding skills can be simultaneously impaired (see the discussion by Manis *et al.*, 1996)?

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Second, what is the underlying cognitive deficit associated with a surface profile of reading disability (Hanley, Hastie and Kay, 1991; Castles and Coltheart, 1993; Ellis, McDougall and Monk, 1996)? Theoretically, demonstrations of functional independence between orthographic and phonological decoding skills might bear on tasks which do not involve reading, but are indirectly related to each route for word decoding. Double dissociations would demonstrate the same phenomenon statistically.

One interesting candidate measure related to orthographic and phonological decoding skills is the distinction between visual and auditory forms of perceptual priming (or implicit memory). Priming refers to the facilitation of task performance by previously studied materials without intentional recollection. This means that participants are not told to remember some specific learning episode, but simply to perform some task in which information that was encoded during that learning episode is subsequently expressed without deliberate recollection (Richardson-Klavehn and Bjork, 1988; Roediger, 1990; Schacter, 1990; Tulving and Schacter, 1990). Memory research has traditionally relied on explicit tests of retention, such as recall and recognition, but there is now an extensive literature in which a dissociation between explicit and implicit memory (priming) is routinely observed, i.e. performance on an explicit test of retention can be independent from performance on an implicit test of retention. Moreover, memory research on perceptual priming has focused almost exclusively on visual tasks, such as word fragment completion, stem completion or word identification (for reviews, see Richardson-Klavehn and Bjork, 1988; Roediger, 1990; Schacter, 1990). Recently, however, priming effects have also been found for auditory stem completion (Bassili, Smith and MacLeod, 1989; McClelland and Pring, 1991), for identification of words masked in white noise (Schacter and Church, 1992), as well as when only F_0 information is provided as target word information (Church and Schacter, 1994).

Up to now, however, only a few studies have provided neuropsychological support for a dissociation between visual and auditory forms of perceptual priming. In one study Schacter *et al.* (1990) described a case of a letter-by-letter reader (PT) who exhibited a marked priming effect on the number of identified words in the visual condition, but failed to produce priming effects in the auditory condition. The opposite pattern of priming effects has been reported by Carlesimo *et al.* (1994). These findings provide support for the existence of perceptual representation systems (PRS) in which implicit memory represents priming of pre-semantic perceptual systems, causing new visual or auditory representations (Schacter, 1990; Tulving and Schacter, 1990; Schacter and Church, 1992; Church and Schacter, 1994). According to this account, different forms of explicit measures of retention (e.g. recall and recognition) are supposed to tap episodic memory, whereas different forms of perceptual priming reflect activations of pre-semantic visual or auditory word form systems. Thus the main prerequisite for perceptual priming to occur is that implicit tests of retention match either visual or auditory representations acquired during a single study episode. Dissociative effects between visual and auditory priming are predicted because each form of perceptual priming is mediated by different word form systems separate from both episodic and semantic representations.

In summary, the present study is an attempt to find independent evidence that orthographic and phonological decoding skills can be selectively impaired in children with reading disorders. If visual and auditory priming effects are mediated by separate word form systems, one would expect children with a surface type of reading disability

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mainly to exhibit priming for auditory materials and children with a phonological type of reading disability to produce more priming for visual materials. Poor readers with both orthographic and phonological weaknesses would be expected to exhibit less priming for both visual and auditory materials.

METHOD

Subjects

Thirty six children (25 boys and 11 girls) with reading disabilities were selected for the experiment. The children were recruited from a pool of children who had had their clinical examination at either the Eve Malmquist Institute for Reading (EMIR) in Norrköping, Sweden, or Ekhaga Habilitation Centre in Linköping, Sweden. The children ranged in age from 9 to 15 years (mean age 11 years; 86% of the children were between 9 and 12 years old). All children were native Swedish speakers and there were no reported signs of sensory or neurological damage or lack of educational opportunity. Most of the children had been diagnosed as dyslexic by trained educational psychologists and all children were receiving some degree of remedial instructions (ranging from 3 to 6 hours a week). Thus their reading age fell well below their chronological age. However, IQ scores were missing for several children and thus we cannot be sure that all children fitted the criteria frequently used for dyslexic readers and, hence, we will continue to use the term poor readers (but see Stanovich, 1996).

Subgroups

To define subgroups of poor readers with either phonological or orthographic weaknesses, two tests designed after Olson *et al.* (1985) were adopted. To measure phonological word decoding skills the children were told to read two pronouncable non-words at a time and their task was to decide as quickly and accurately as possible which non-word sounded like a real word in Swedish. As non-words are visually unfamiliar, they cannot be identified orthographically and thus the children are forced to employ a phonological decoding strategy. There were 120 non-word pairs in the test with 20 pairs on each page and they were allowed to work with the test for only 2 minutes. The children were instructed to circle one of the words presented in each pair that sounded like a real word.

Orthographic word decoding skill was measured by having the children read word pairs and identify as quickly and accurately as possible the word that was correctly spelled. In this task the phonological codes for the pairs of stimuli were identical, but only one word was spelled correctly, i.e. both stimuli would be pronounced as a real word in Swedish. Thus the children must rely on their memory for word-specific orthographic patterns to make a correct response. The number of word pairs, the time limit and instructions were the same as for the phonological decoding test. For both tests skill in orthographic and phonological word decoding was recorded as the difference between the number of correctly and falsely identified words.

The two subgroups were then defined as the discrepancy between orthographic and phonological decoding skills. Because the means in each decoding test were not comparable (it is normally much easier to perform the orthographic task), we used a simple standard score procedure to define our subgroups. Thus we transformed the

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Table 1. Mean age, orthographic decoding skills and phonological decoding skills for the three subgroups of poor readers (standard deviations and ranges in parentheses)

	Surface subgroup	Phonological subgroup	Mixed subgroup
Age	10.2 (1.3, 9–12)	11.0 (1.9, 9–14)	11.1 (1.8, 9–16)
Orthographic decoding	9.0 (4.1, 4–13)	40.0 (9.4, 32–51)	19.0 (11.8, 1–42)
Phonological decoding	25.0 (3.6, 21–31)	11.0 (5.9, 4–20)	16.0 (7.4, 1–31)

raw scores on each decoding test into standard scores and then calculated discrepancy scores between orthographic and phonological skills (i.e. expressing relative skill in either orthographic or phonological world decoding in standard scores). Using a cut-off score of one standard deviation above or below the mean, six children were very low in phonological decoding relative to their skills in orthographic decoding and five children were poor in orthographic decoding reading relative to their skill in phonological decoding. This standard score procedure also demonstrated that most of the children in our group ($n=25$) did not dissociate in their word decoding skills. Hereafter, these subgroups of different reading disabilities will be denoted the phonological subgroup (i.e. poor phonological decoding skills), the surface subgroup (i.e. poor orthographic decoding skills) and the mixed subgroup (i.e. poor in both phonological and orthographic decoding skills).

To study whether the children in each subgroup performed within a normal range, we compared mean performances on each decoding task in normal readers reflecting the chronological age range of the dyslexic subgroups (see Table 1)[1]. These chronological age norms were 18, 23, 27, 31, 35 and 39 points on average in the phonological decoding test for 9, 10, 11, 12, 13 and 14 year old children and 24, 34, 46, 55, 67 and 83 points in the orthographic decoding test. Comparisons revealed that the surface subgroup was comparable with same-age normal readers in phonological decoding (25 vs. 23), whereas their orthographic decoding skills were extremely poor (9 vs. 36). The phonological subgroup were very poor in phonological decoding compared with same-age controls (12 vs. 27), but they were not fully comparable with same-age controls in orthographic decoding (40 compared to 47). Thus we cannot conclude that all phonological dyslexics were reading exception words at a level comparable with same-age normal readers. The reason was that orthographic decoding exhibited in one child (34 points) in this subgroup was clearly below the mean for the corresponding age (83 points in average). For this reason, this child was excluded from further analysis and the phonological subgroup was reduced from six to five children. Finally, the mixed subgroup was poor in both decoding tasks compared with same-age normal readers (19 vs. 46 in orthographic decoding and 16 vs. 28 in phonological decoding). From these comparisons with normal word decoding skills we can conclude that our subgroups of poor readers perform at least two years behind their chronological age in either orthographic or phonological decoding, or both[2]. Finally, mean ages were almost identical in the three subgroups.

Materials and procedure

The explicit and implicit procedure had two parts, corresponding to the visual and auditory modality in a balanced order design (i.e. half of the children started with the

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visual modality). A letter matching task and a verbal fluency task to control for potential visual or semantic weaknesses were also performed. The letter matching task was also used as a distractor task between the explicit and implicit tests of retention in both the visual and auditory modality. All children were tested individually and they all started to complete the two word decoding tests.

The study phase and explicit test of retention

A total number of 32 target words and 16 distractor words were selected (4–6 letters in length) in the visual modality. All words were regular nouns frequently used in written Swedish. The target words were randomly assigned to four lists of 12 words in each and the distractor words were placed at positions 1, 6, 7 and 12 in each list. In the study episode the children were told to read one word at a time at their own pace (i.e. each word was presented only once) and that a new word would appear on the computer screen as soon as they pressed a button. The time needed for reading each word was registered by the computer program. They were also instructed that they would be asked verbally to recall as many words as possible after reading a list of 12 words. The proportion of correctly recalled words was taken as a measure of explicit memory performance.

The explicit auditory test of retention was identical to that of the visual modality, except that the words were now presented aurally on a tape recorder. The words were played to the children at volumes corresponding to normal conversational levels with a speed of one word every fifth second. Thirty two new target words and 16 new distractor words were selected for the auditory modality. The words were matched in word length and frequency to those used in the visual modality and they were all Swedish nours. The words were also divided into four lists, each containing 12 words, and the distractor words were placed at positions 1, 6, 7 and 12 in each list heard.

The letter matching task

Immediately following word presentation and recall of the study lists in both modalities, the children proceeded to the letter matching task. In this task pairs of letters were presented on the screen and the children had to decide as quickly as possible whether or not the two letters matched each other physically (Posner *et al.*, 1969). Decision latencies were measured by the computer program. The task was divided into two parts and a total number of 32 pairs of letters were presented in each part, of which 16 pairs in each part were identical. Thus the first part was used as a distractor task in the visual modality and the second part of the test was used as a distractor task in the auditory modality.

Implicit tests of retention

To measure implicit memory in the visual modality, the children received a word stem completion test with the instruction verbally to complete the stem by the first word that came to mind. No references to the study phase were made. Each stem was composed of the first two letters of the corresponding target word presented in the study phase (i.e. there was a total number of 32 target words) followed by an appropriate number of dashes and they were presented one at a time on the computer screen. There were also 16 distractor stems included in the completion test. These distractor stems were included to reduce the risk that some of the children would become conscious of the relation between the study phase and the word stem completion test.

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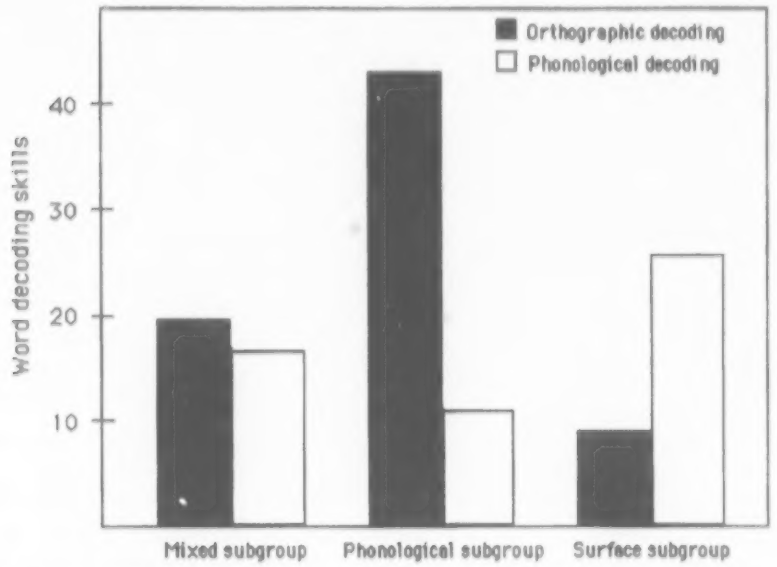

Figure 1. Mean performance in the two word decoding tests for the three subgroups of poor readers.

To measure implicit memory in the auditory modality, the children completed an auditory identification test in which all target words from the study phase together with 16 new distractor words were masked by white noise. In a pilot study baseline performances for three different levels of white noise were selected to make sure that the proportion of non-primed completion varied between 25 and 40%. The children were instructed to verbally repeat each word with the first word that came to mind.

Verbal fluency

The final task was a verbal fluency task in which the children were asked to generate as many words as possible from two different semantic categories (fruits and vegetables); 30 seconds were allowed for each category.

Design

The design was a mixed factorial design with two factors and the explicit and implicit tests of retention as two dependent measures. The between-subjects factor was the group manipulation (surface, phonological and mixed subgroups), whereas the within-subjects variable was the presentation modality (visual or auditory).

RESULTS AND DISCUSSION

The standard score procedure, used to define subgroups, does not show at what level these three subgroups perform on each decoding task, i.e. if there are any real differences between their orthographic and phonological decoding skills. The performance of the three groups on each word decoding test is shown in Figure 1.

A 3 × 2 mixed ANOVA (with subgroups as a between-subjects factor and decoding task as a within-subjects factor) showed that there was a significant effect for decoding

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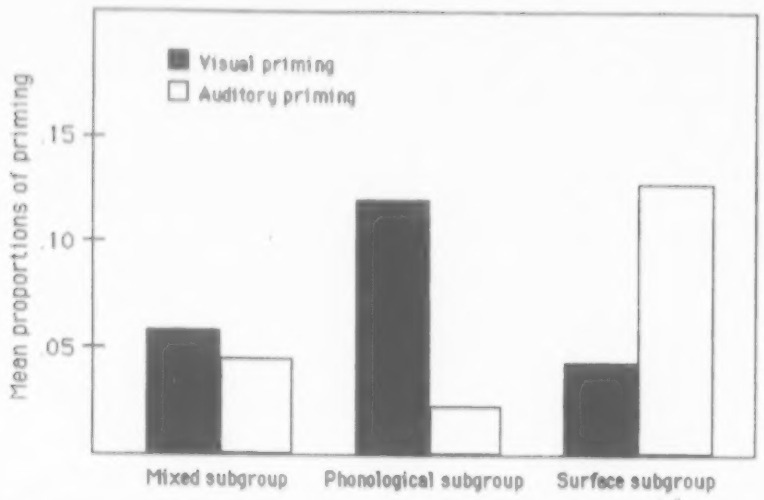

Figure 2. Mean proportions of visual and auditory priming for the three subgroups of poor readers.

task, $F(2,32)=10.81$, $MS_e=23.9$, $p<0.01$, confirming that the orthographic decoding task is easier to perform compared with the phonological decoding task. There was no main effect for group, $F(2,32)=2,10$, $MS_e=141$, $p>0.05$. Finally, there was a significant interaction between decoding task and subgroups, $F(2,32)=57.93$, $MS_e=23.9$, $p<0.0001$. This interaction reflects a double dissociation between surface and phonological subgroups and their orthographic and phonological word decoding skills. The interaction also indicates that the mixed subgroup was impaired in both word decoding tasks.

Furthermore, a one-way ANOVA showed no significant main effect for subgroups for verbal fluency, $F(2,32)=0.12$, $MS_e=1.6$, $p>0.05$ (means were 16.0, 16.2 and 15.4 generated words for surface, phonological and mixed subgroups respectively) nor for decision latencies in the Posner task, $F(2,32)=0.09$, $MS_e=0.002$, $p>0.05$ (means were 0.88, 0.84 and 0.85 seconds for surface, phonological and mixed subgroups respectively). These findings are important because they suggest that differences in word decoding skills in the subgroups are not attributable to an impairment in the semantic system nor to deficient analytical visual processing. It is also clear that an impairment in orthographic word decoding is not due to a deficit in the ability to visually identify forms of single letters, but rather to represent word-specific orthographic knowledge.

To evaluate the priming effects, baseline performances on each implicit test of retention were selected from 40 children randomly selected from three different schools (ranging from 10 to 14 years of age). Their task was to complete the word stem completion task and the auditory identification task without having been exposed to the target words previously. Baseline performances were 0.081 for the word stem completion test (i.e. on average 2.6 word stems were completed with target words) and 0.31 for the auditory identification task (i.e. on average 10 words were identified from the lists of target words used in the auditory modality). The difference between mean properties of target words generated in the implicit tests of retention and these baseline scores constituted the magnitudes of visual or auditory priming. The magnitudes of visual and auditory priming for each subgroup are displayed in Figure 2.

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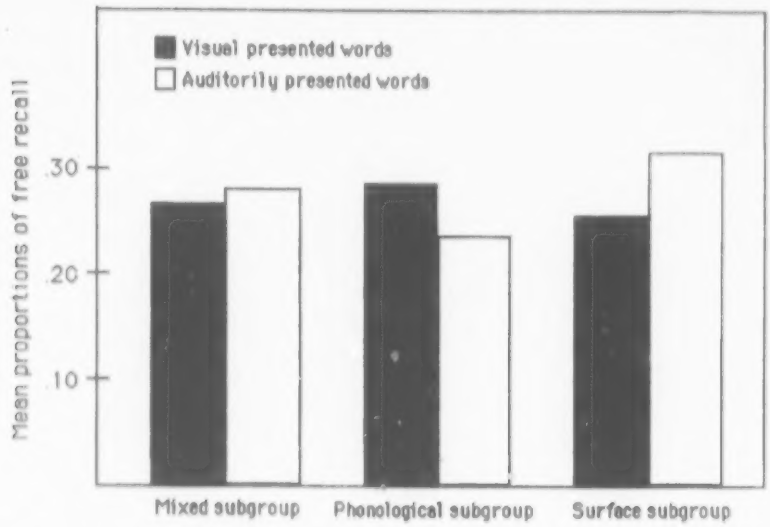

Figure 3. Mean proportions of free recall of visually and aurally presented words for the three subgroups of poor readers.

In this analysis there was no main effect for subgroups, $F(2,32)=0.59$, $MS_e=0.01$, $p>0.05$, suggesting no differences in the magnitudes of priming across the subgroups of poor readers. Furthermore, there was no main difference in the magnitude of priming between the visual and the auditory modality, $F(1,32)=0.29$, $MS_e=0.01$, $p>0.05$. The critical outcome, however, was a significant interaction between subgroups and modality, $F(2,32)=4.90$, $MS_e=0.006$, $p=0.01$. Simple main effects (adjusted for unequal n) showed that the phonological subgroup exhibited more visual priming compared with auditory priming, $F(1,32)=5.33$, $MS_e=0.004$, $p<0.05$, and that the opposite pattern was true for the surface subgroup, $F(1,32)=4.27$, $MS_e=0.004$, $p<0.05$. Furthermore, planned comparisons showed a significant difference in the magnitude of auditory priming between surface and mixed subgroups, $F(1,32)=5.15$, $MS_e=0.006$, $p<0.05$, and a tendency for the phonological subgroup to show significantly more visual priming than the mixed subgroup, $F(1,32)=2,75$, $MS_e=0.006$, $p<0.10$. Thus, these findings provide support for a double dissociation such that the surface subgroup produced more auditory compared with visual priming, whereas the phonological subgroup showed more visual compared with auditory priming.

Figure 3 displays the mean proportions of free recall as a function of subgroups and presentation modality (visually vs. aurally presented words), showing no main effect for group, $F(2,32)=0.28$, $MS_e=0.01$, $p>0.05$. Also, there was no main effect for modality, $F(1,32)=0.14$, $MS_e=0.01$, $p>0.05$, and finally, there was no interaction between group and modality, $F(2,32)=1.97$, $MS_e=0.01$, $p>0.05$. These free recall data are important because they provide evidence that differences in the magnitude of visual and auditory priming are not attributable to the use of explicit retrieval strategies.

So far we have identified phonological and surface subtypes of reading disability by measuring the magnitude of visual and auditory priming and a mixed subgroup poor in both phonological and orthographic word decoding who displayed low levels of both visual and auditory priming. At this stage we decided to repeat the tests in a

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group of age-matched normal readers. Ten children (six boys and four girls; mean age 11 years; range 10–13 years) were randomly selected from one elementary school in Linköping. All children were native Swedish speakers and all children were progressing normally in reading.

First, phonological decoding in these age-matched controls was almost identical with the surface subgroup (23 vs. 25) and orthographic decoding was comparable with the phonological subgroup (44 vs 40). These results suggest that age-matched controls perform normally on both decoding tasks and that phonological and surface subgroups of poor readers perform normally in either orthographic or phonological decoding. Second, age-matched controls exhibited approximately the same amount of visual and auditory priming compared with phonological and surface subgroups. To be more precise, mean visual priming was 0.104 for normal readers, compared with 0.118 for the phonological subgroup, and mean auditory priming was 0.148 compared with 0.124 for the surface subgroup. Third, and finally, age-matched normal readers perform much better on explicit memory for both aurally and visually presented words (0.37 and 0.39). These findings are consistent with the pattern of results found for the subgroups of poor readers.

GENERAL CONCLUSIONS

The results of this study replicate previous findings showing that some children with reading disorders exhibit discrepancies between orthographic and phonological word decoding skills (Castles and Coltheart, 1993; Manis *et al.*, 1996; Stanovich, Siegel and Gottardo, 1997). Using the one standard deviation cut-off for the difference between orthographic and phonological decoding skills, we found 10 cases out of 35 (28%) with 'pure' orthographic or 'pure' phonological decoding weaknesses.

In addition, our results also provide a new empirical case in which it might be possible to examine the underlying functional architecture in different subtypes of reading disorders. One discussion raised by several authors concerns whether a dissociation between orthographic and phonological decoding skills is related to an impairment in word decoding or whether there is a difference in the use of word decoding strategies (Snowling, 1987; Wilding, 1989; Castles and Coltheart, 1993). However, the procedure to measure both auditory and visual forms of implicit memory (priming) might help solve this problem to separate word decoding strategies from word decoding weaknesses. Thus a dissociation between orthographic and phonological decoding weaknesses in children with reading disabilities that is mirrored by a similar dissociation between the degree of visual and auditory priming provides independent support for a pattern of more stable weaknesses rather than differences in the use of strategies. The obvious reason is that perceptual priming effects are not mediated by explicit retrieval strategies, but attributable to visual or auditory representations in the absence of conscious recollection, and thus there is little room for strategies. This argument is also strengthened by the fact that there were no differences between the subgroups of poor readers on explicit tests of retention, i.e. a dissociation between explicit memory and levels of priming for visual or aurally presented words. This argument is also supported by the fact that the levels of priming effects observed in an age-matched group of normal readers were almost identical to those exhibited by subgroups of poor readers, despite the fact that they performed much better on explicit tests of retention.

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With respect to the underlying functional architectures in different subgroups of reading disabilities, several studies have reported a relation between phonological decoding and performance on a variety of tasks measuring phonological awareness (see Wagner and Torgesen, 1987; Rack, Snowling and Olson, 1992; Share and Stanovich, 1995, for reviews). Our finding that children with pure phonological deficits exhibited more visual compared with auditory priming is consistent with the view that phonological processing problems are one of the core deficits in the phonological subtype of reading disability. However, our study adds a new kind of empirical support for this assumption by the assessment of auditory priming effects.

In contrast, there was no clear evidence of any underlying cognitive impairment reported that might be associated with a weakness in orthographic word decoding (Ellis, McDougall and Monk, 1996; Hanley, Hastie and Kay, 1991). Our contribution in this context is that perceptual priming should be seen as an indicator of the strength with which visual and auditory information is implicitly extracted and thus the ability to represent either orthographic features in written words or spectral and temporal features of spoken words. This means that the primary function of perceptual representation systems is to subserve perceptual recognition (Schacter, 1990). Given that the priming effects demonstrated in this paper are mediated by two separate word form systems, it is reasonable to argue that any failure to show priming effects in one particular modality represents one possible cause to different problems with word decoding in poor readers. On the distinction between orthographic and phonological word decoding weaknesses, this assumption suggests that the primary problem in the surface subgroup is in the visual word form system, hence the inability to represent orthographic structures of words as a clue to their identification. These suggestions are in line with a dual-route model of word decoding skills. Thus a double dissociation between orthographic and phonological decoding deficits and the magnitudes of visual and auditory priming suggest that there might be two separate routes available in word decoding and that these routes can be simultaneously impaired.

It should be made clear, however, that any dissociation between subtypes of reading disabilities or difference between age-matched normal readers and poor or dyslexic readers might also be explained by considering differences in the developmental stage reached by poor readers, for example the amount of exposure to printed words (Stanovich, Siegel and Gottardo, 1997). Thus, even if it was possible to statistically define different subtypes of reading disability, it would still be debatable as to how to account for these findings. In that sense, the present findings are suggestive rather than conclusive and need to be replicated. To address this question as well as generalizing the present findings, further research using this perceptual priming paradigm should include reading-matched controls and a focus more on longitudinal investigations.

In conclusion, it is possible to independently dissociate patterns of orthographic weakness from phonological problems and each route available for word decoding can be selectively impaired. The experiment also suggests one candidate as a predictor of orthographic word decoding weaknesses, i.e. an impairment in a pre-semantic visual word form system and, thus, extracting physical features about the visual form and structure embedded in written language. Finally, by using procedures from memory research focusing on the distinction between explicit and implicit memory, we suggest that we have a new set of both theoretical and methodological tools to study varieties of reading disability.

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NOTES

[1] These norms were selected from two other studies where we used identical decoding tasks in age intervals ranging from 9 to 12 years (the number of children in each age interval ranged from 70 to 80). Norms for the five dyslexic children between 13 and 15 years were based on samples ranging from 10 to 20 normal readers. However, the norms for each age interval were almost identical to those selected by Dr Åke Olofson at Umeå university, Sweden (based on 300–400 children in each age interval), but in his case there were three exception words or non-words in each item instead of pairs in the decoding tasks.

[2] One issue that can be raised with regard to the word decoding tests is the question of reliability. We have used identical tests in a longitudinal study and found test–retest reliabilities for three different groups (normal readers 8 and 10 years old and poor readers 10 years old) between 0.78 and 0.82 for the orthographic decoding test and between 0.61 and 0.79 for the phonological decoding test.

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Study IV

Cognitive abilities and print exposure in surface and phonological types of reading disability

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NOTES

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ABSTRACT

Subgroups of reading disabled children were identified using the regression method introduced by Castles and Coltheart (1993). Children who were poor in phonological compared to orthographic word decoding were identified as phonological type subjects and children who were poor in orthographic compared to phonological decoding were identified as surface type subjects. The results replicated previous findings that if categorisations are based on comparisons with younger, reading-level matched controls instead of age matched controls, the number of surface type children is significantly reduced. Surface type children performed below the other groups on most cognitive measures and reported that there were less books at their homes, whereas phonological type children showed a specific deficit in phonological word decoding. The results provided additional support for the hypothesis that the surface type of reading disability can be characterised as a general developmental delay.

Cognitive abilities and print exposure in surface and phonological types of reading disability

In the field of reading disability research there have been many attempts to categorise reading disabled individuals into different subtypes. For example, according to the IQ-discrepancy criterion, individuals are categorised into subgroups based on the discrepancy between IQ and reading skills. If the reading skills of a particular individual are below what would be expected from the IQ score, that individual qualifies as a developmental dyslexic. However, this procedure has been severely criticised on many different levels and has not proven useful for defining subgroups that are qualitatively different from each other (Felton & Wood, 1992; Fletcher et al., 1994; Fredman & Stevenson, 1988; Samuelsson et al, 1999; Siegel 1992; Stanovich & Siegel, 1994). Ideally, a subgrouping procedure should yield subgroups that are distinct and qualitatively different from each other. Also, the procedure should be outcome-based, that is, it should suggest different interventions for the resulting subgroups (Aaron, 1997). One promising procedure, inspired by studies of the acquired dyslexias (Dérouesné & Beauvois, 1979; Newcombe & Marshall, 1985; Shallice & Warrington, 1980), is based on the variations in word decoding skills among reading disabled individuals. Unlike the IQ-discrepancy criterion, this procedure is very closely linked to the process of reading itself.

Research on word decoding strategies has identified two main routes from print to meaning: phonological and orthographic word decoding. Phonological word decoding refers to an identification of words based on letter-sound conversion and orthographic word decoding refers to a direct recognition of words on a visual basis. Stage models of reading development have regarded phonological word decoding as the stage which precedes orthographic word decoding (Frith, 1985; Høien & Lundberg, 1988). However, such general models do not explain individual differences in

reading development precisely and do not recognize that phonological and orthographic knowledge probably develops continuously and, at least to some extent, in parallel (Ehri, 1987, 1993). Even so, in general there seems to be a gradual shift from phonological decoding to more orthographic and automatic processing of written language (Ehri, 1987; Ehri & Wilce, 1987; Frith, 1985; Juel, Griffith, & Gough, 1986; Samuelsson, Gustafson, & Rönnberg, 1996; Share, 1995).

There are some empirical demonstrations that phonological and orthographic word decoding can be selectively impaired also in developmental reading disabilities (Castles & Coltheart, 1993; Manis et al., 1996; Samuelsson, Finnström, Leijon, & Mård, in press; Stanovich, Siegel, & Gottardo, 1997). In the surface type of reading disability, the orthographic route from print to meaning is impaired and the individual tends to rely on the phonological route, whereas the opposite is true for the phonological type of reading disability. This categorisation into subgroups is to some extent arbitrary in that there are no given cut-off points between groups.

Castles and Coltheart (1993) developed a method for subgrouping based on regression analysis. First, two regression analyses were performed with two variables: nonword reading and irregular word reading. In one analysis, nonword reading was used as the predictor variable and in the other irregular word reading was the predictor. These regression lines (with 90% confidence intervals) were then superimposed on the corresponding scatter plot of dyslexic individuals. Individuals were then categorised as phonological dyslexics or surface dyslexics if they were below the 90% confidence limit of the corresponding regression analysis. This procedure yielded 29 phonological dyslexics exhibiting nonword reading inferior to their irregular word reading and 16 surface dyslexics exhibiting irregular word reading inferior to their nonword reading, whereas 8 dyslexics did not show any dissociaton between the two decoding skills (Castles & Coltheart,

1993). However, this study has been criticised mainly because the control group consisted of age matched controls who were performing much better on measures of word decoding than the dyslexics (Manis et al., 1996; Stanovich et al, 1997; see also Bryant & Impey, 1986).

Stanovich et al. (1997) performed a re-analysis of the Castles and Coltheart (1993) data with a reading-level matched control group consisting of the younger children from the original control group. When this new benchmark for categorisations was used, 15 phonological dyslexics and only 2 surface dyslexics were identified. This result is consistent with the findings of Manis et al., (1996) where 17 phonological and 15 surface dyslexics were identified from a total sample of 51 dyslexics when age matched controls were used. When the analyses were repeated with reading-level matched controls, 12 children remained categorised as phonological dyslexics whereas only one of the surface dyslexics remained in this subgroup. Stanovich et al. (1997) used the same regression-based procedure on younger children (in grade 3) and found very similar results. Of the 68 reading disabled children, 17 phonological and 15 surface dyslexics were found when compared to age matched controls. When the regression line was based on reading-level matched controls, 17 phonological dyslexics were identified but only one surface dyslexic. Interestingly, when the subgroups defined by comparisons to age matched controls were compared to reading matched controls on measures other than word decoding skills, phonological dyslexics showed deficits in phonological sensitivity, working memory and syntactic processing. Surface dyslexics, on the other hand, showed a cognitive profile very similar to that of the reading-level matched controls (Stanovich et al., 1997).

These results support the hypothesis that phonological dyslexia reflects true developmental deviancy; that is, phonological dyslexics seem to differ qualitatively from reading-level matched controls. Phonological dyslexics

seem to fit the typical, general account of developmental dyslexia, where core phonological processing deficits are assumed to cause difficulties in word decoding (Lundberg & Høien, 1989; Snowling, 1981; Stanovich & Siegel, 1994). Surface dyslexia, in contrast, might be characterised as a general developmental delay since surface dyslexics do not seem to differ from younger, reading-level matched children (Bryant & Impey, 1986; Manis et al., 1996; Plaut & Shallice, 1994; Samuelsson et al., in press; Stanovich et al., 1997). It should be noted, however, that even if there are children who show a relative deficit in one word decoding strategy compared to another, many reading disabled children do not show such a discrepancy. Thus, there are three subgroups that should be considered in the analyses: surface type, phonological type, and the mixed type of reading disability.

Independent support for the validity of the subgroups of phonological and surface dyslexia is still largely lacking, especially with regards to surface dyslexia (Castles, Datta, Gayan, & Olson, 1999; Stanovich et al., 1997). Findings for cognitive profiles of the two subgroups in Stanovich et al. (1997) need to be replicated and further examined. In particular, further research should investigate the possibility that the two subtypes may arise from a combination of cognitive factors and environmental factors, such as print exposure and method of reading instruction (Castles et al., 1999; Clay, 1987; Manis et al., 1996; Stanovich et al., 1997). For example, it has been hypothesised that surface dyslexia may result from less severe phonological deficits in combination with limited exposure to print (Castles et al., 1999; Stanovich et al., 1997). Empirical support is still lacking for this hypothesis, but in the present study I will take a step in that direction by examining both cognitive factors and print exposure in relation to the phonological type, surface type, and mixed type of reading disability.

The present study also builds upon the main finding of a previous study where an interaction between word decoding skills and implicit memory

performance was found (Samuelsson, Gustafson, & Rönnberg, 1998). Subgroups were here defined by a standard score procedure in which the discrepancy between orthographic and phonological decoding was first calculated. Then, individuals who were at least one standard deviation above or below the mean were defined as phonological type or orthographic type, respectively. The results demonstrated a double dissociation, such that poor readers with a surface type of reading disability (5 subjects) produced more auditory than visual repetition priming for words, whereas poor readers with a phonological type of reading disability (5 subjects) showed more visual than auditory repetition priming. This study thus suggests that implicit memory might be one candidate for providing independent support for underlying cognitive differences between the two subgroups (see also Samuelsson, in press; Samuelsson, Bogges, & Karlsson, in press).

Memory has been extensively studied in relation to reading (Baddeley, 1978; Brady, 1991; Ellis & Miles, 1981; Gathercole, Willis, & Baddeley, 1991; Macaruso, Locke, Smith, & Powers, 1996) and subgroups of reading disability (Bateman, 1968; Howes, Bigler, Lawson, & Burlingame, 1999; Johnson & Myklebust, 1967). The focus in these studies has mainly been on short term memory or working memory. Since strong evidence has been found that reading disability is often associated with phonological deficits, it is not surprising that reading disabled individuals perform below normal on measures of verbal short term memory or working memory.

However, short term memory, or traditional explicit measures of long term memory such as free recall, are not the only types of memory related to the process of reading. When reading familiar words we continuously make use of lower level, perceptual representations of these words. The nature of these perceptual representations might be studied by means of implicit (indirect or incidental) memory tasks, such as word stem completion or perceptual identification. The critical measure in these tests are repetition

priming effects, which refer to facilitation of task performance by previously studied items without intentional recollection.

Several studies have provided evidence for a dissociation between explicit and implicit tests of retention (for reviews see Roediger & McDermott, 1993; Richardson-Klavehn, Gardiner, & Java, 1996; Schacter, Chiu, & Ochsner, 1993). Proponents of a multiple memory systems view have attributed priming effects in implicit memory tasks to the workings of an implicit memory system, functioning independently of explicit memory (Schacter, 1992; Tulving & Schacter, 1990). Schacter (1990) hypothesised that different perceptual representation systems (PRS) are responsible for implicit processing and that this processing is presemantic in nature. One of these subsystems in implicit memory, the visual word form system, is assumed to be associated with the visual form and structure for words (Schacter, 1990; Schacter et al., 1990), while another subsystem, an auditory perceptual representation system, is assumed to be involved in auditory perceptual processing of words (Schacter & Church 1992; see also Ellis & Young, 1988).

Studies demonstrating depth of processing effects on the magnitude of priming in implicit tests such as word stem completion have questioned the presemantic and implicit status of such tasks (Brown & Mitchell, 1994; Challis & Brodbeck, 1992; Thapar & Greene, 1994). However, a recent study by Richardson-Klavehn and Gardiner (1998) indicates that depth of processing effects on the amount of priming during stem completion reflects lexical processes rather than contamination by voluntary retrieval or prior conceptual processing. Thus, word stem completion could be an appropriate measure of implicit visual lexical processing deficits.

The present study examined the relationship between visual and auditory priming for words, as well as orthographic and phonological word decoding skills in reading disabled children. The previous study (Samuelsson et al., 1998) indicated that implicit memory for words was critical in explaining the

use of word decoding strategies but did not asses any external factors such as exposure to written language and what kind of reading instruction the children had received in school. In the present study the reading habits of the children were examined by a questionnaire. Also, age matched controls were selected from the same classrooms as reading disabled children in order to minimise the potential confounding effects of differences in reading instruction. To further explore the effects of environmental factors in the subgroups of reading disabled children implicit memory was examined for both high frequency and low frequency words. Low frequency words would be expected to be more sensitive to limited print exposure than high frequency words. If the perceptual representation systems in implicit memory are generally impaired one would expect to find reduced repetition priming regardless of word frequency.

In the present study, subgroups of reading disabled children were identified based on the regression lines of both age matched controls and reading-level matched controls. The resulting subgroups of surface type, phonological type, and mixed type children, were then compared on a variety of cognitive measures as well as on measures of print exposure.

METHOD

Participants

A total of 108 subjects participated in the study. The parents of the children had signed a letter of consent allowing their children to participate. The subjects belonged to three different groups; reading disabled (RD) children (n=53), age matched controls (n=29), and reading-level (RL) matched controls (n=26). The subjects were selected from seven different schools located in the south-east of Sweden. The schools were located in primarily middle-class communities. Children with gross neurological disturbances, sensory deficits, and children who did not speak Swedish as their first language were excluded from the study.

Reading disabled children were defined as children in grades 4-6 who received special instruction in reading because of reading difficulties at the time of the study. Fifty-three RD children were selected from 6 different schools and 24 different classrooms. These children belonged to ordinary classrooms but received additional reading instruction, consisting of direct instruction and training in reading and spelling as well as some phonological awareness training, by special instruction teachers. RD children had been assigned to special instruction based on the results of various formal reading tests in combination with teacher ratings. The measure of reading ability demonstrated that the sample of RD children performed well below the age matched controls of the present study (m=20.5 versus m=30.8; see Table 1), and also below a group of normal readers in grade 4 examined in a previous study (Gustafson, Samuelsson, & Rönnberg, 2000; m=26.5, n=83). The reading disabled children ranged in age from 9 to 12 years, (m=11 years, 2 months).

Twenty-nine age matched controls were randomly selected from 15 of the classrooms supplying RD children. The matching was achieved by selecting approximately the same proportions of age matched controls and RD children from grades 4-6. Age matched controls ranged in age from 10 to 12 years (m=11 years, 0 months).

Twenty-six reading-level matched controls were randomly selected from three classrooms of another primary school in the same school district. The mean score on reading ability was matched with the mean score of RD children already in the initial sample of 26 RL matched controls, making further exclusions or additions of participants unnecessary. RL matched controls ranged in age from 8 to 9 years (m= 8 years, 11 months).

In order to assess priming effects, baseline data on the two implicit memory tests were obtained from three additional groups of children. These children only completed the visual and auditory implicit memory test,

without any previous study of the words. Sixteen children supplied baseline data for RD children, 16 for age matched controls, and 18 for RL matched controls. These children were selected from the same schools as the other participants and exactly the same criteria for selection were used as for their corresponding group.

Materials and procedure

The same experimenter administered all tests to all subjects who participated in the study. Each test session began with three pen and paper tasks which the children received in small groups of about 6-8 subjects at a time. Each child responded individually on a response sheet.

Reading ability. Reading ability was assessed by a Swedish test developed by Malmquist (1977). The children silently read twelve short passages of text each followed by one to four simple multiple choice questions with four response alternatives for each question. The total number of questions was 33 and the time limit was 8 minutes. The children were instructed to read as quickly and accurately as possible and to choose one of the response alternatives after each question and mark the corresponding answering box. The test was timed, and the number of correct responses was taken as a measure of their reading ability.

Listening comprehension. The second test was a listening comprehension test derived from a Swedish standard test of reading ability. The test contained 30 short passages of text, each followed by a multiple choice question with three response alternatives. This reading ability test was transformed into auditory form by the author. Thirty short passages of text, each followed by a question with four response alternatives, were digitally recorded in a recording studio at the Department of Technical Audiology, Linköping University Hospital. The recording levels and lengths of pauses between questions were adjusted and the final test version was then transferred to an audio tape.

Print exposure. A questionnaire containing 10 written questions about reading habits was developed by the author. In the questionnaire the children were asked how many books there were at their homes, how often they read different kinds of publications, how often they had homework in reading, and if they estimated that they spent more, less, or an equal amount of time reading compared to their comrades (all were multiple choice questions). Effort had been made to keep the questions short and straightforward. The questionnaire was answered with the experimenter present in the room and the children were instructed to ask for help if they had any problems understanding the questions or filling in the answers. If a child had very severe reading difficulties the experimenter read the questions and multiple choice answers aloud for that child. The answers were coded from 1-3, 1-4 or 1-6 depending on the number of response alternatives, where a low number indicated low print exposure and vice versa.

The remaining tests were administered individually. First, explicit and implicit memory were examined in both modalities.

The study phase and explicit test of retention. In the visual modality, the subjects were asked to memorize words that were presented to them on a computer screen. The child was asked to read the word on the screen and then immediately press a button so that the next word would appear. After 8 words had been presented, the experimenter said "stop", waited for three seconds, and then asked the child to recall and verbally report as many words as possible in no particular order. This was repeated with three new sets, each containing 8 words. The total number of words correctly recalled was taken as a measure of visual explicit memory and thus the maximum score was 32.

Here, it should be noted that the visual explicit memory task was only visual with regard to modality of stimuli presentation and that it also

included a phonological component, because the decoding of the words would be expected to activate their phonological representations (cf. Liberman, 1999). Although most children read the words out aloud in the study phase, some variations in the amount of vocalisation of the words were allowed due to the strong strategic preferences of the children (see the Discussion for possible implications).

The study phase and explicit test of retention in the auditory modality was identical to that of the visual modality except that four new sets of words were now presented auditorily on a tape recorder. Thus, after the child heard 8 words the tape recorder was stopped, the experimenter waited 3 seconds, and then asked the subject to recall as many of these words as possible in no particular order. The words were digitally recorded with the recording levels and lengths of pauses between words (3 seconds) having been equalised before being transferred to audio tape.

Modality was a within-subjects variable and therefore a subject received different words in the visual and auditory modalities. Thus, there were two test versions, each containing 32 Swedish target words. Each version contained 28 nouns (4 animates and 24 inanimates) and 4 verbs, 16 regular and 16 irregular words, and 16 high frequency and 16 low frequency words. All words were two-syllables with a length of 5-6 letters. For every word in the first set there was a corresponding word, matched on word class, regularity, and frequency, in the same position in the second test version. Unfortunately, there is no useful word frequency lists for Swedish words. However, the selected words were either quite frequent (e.g., "kvinna" ["woman" in English]) or unusual but still understandable for children (e.g., "demon" ["demon" in English]).

To eliminate the possibility that the two different sets of words would confound the results and to avoid order effects of modality, half of the subjects initially received the first set of words in the visual modality (in the

explicit and implicit memory tests) and then the second set of words in the auditory modality. The other half of the subjects initially received the first set of words in the auditory modality and then the second set of words in the visual modality. Thus, a particular word occurred just as often in the visual as in the auditory modality across subjects. Performances on the explicit memory tests were also very similar for the two different sets of words (m=12.8 and 12.6 in the visual modality and m=15.0 and 15.3 in the auditory modality, n=108).

Arithmetic. Between the explicit and implicit memory test in both modalities an arithmetic test was administered. The subject received a mix of simple addition and subtraction tasks (i.e., "5+1=__" and "9-2=__") on a sheet of paper and were asked to complete as many of them as possible during one minute. All subjects received two different versions of this test, one between the visual explicit test and visual implicit test and the other between the auditory explicit test and auditory implicit test and the sum of correct answers on these two test versions were used as a measure of arithmetic skill. The large number of items (60 for each version) made it impossible to complete all of them in one minute. This test also had the function of being a distractor task to reduce the risk of explicit memory strategies being used in the implicit tests of retention.

Implicit tests of retention. A word stem completion test was used as a measure of implicit memory in the visual modality. Fifty-two 3-letter word stems (followed by a number of dashes) were presented one at a time on the computer screen. The children were instructed to verbally complete the word stems with the first Swedish word that came to mind. They then pressed a button and the next word stem appeared on the screen. No references to the study phase were made. Thirty-two of the stems were composed of the first three letters of the corresponding target words previously presented in the study phase. In addition, there were 20 distractor

stems not corresponding to any word in the study phase, which were solely included to reduce the risk that the children would become conscious of the relation between the stem completion test and the study phase. The first two word stems presented to the subjects were distractor stems and the remaining 18 distractors were randomly assigned to positions and thus spread throughout the test.

The implicit memory test in the auditory modality consisted of an auditory identification task in which the 32 target words from the study phase were mixed with 20 new distractor words (placed in the same positions as in the stem completion test) and masked by white noise. The words were digitally recorded as in the afore-mentioned auditory tests. The lengths of pauses between words (5 seconds) and the signal/noise ratio were equalised and then transferred to the audio tape. The children were asked to verbally repeat each word with the first Swedish word that came to mind. Half of the target words in the implicit memory tests (and in the explicit memory tests) were high frequency words and half were low frequency words.

The proportion of target words being produced/identified, minus the mean performance of the corresponding baseline group, was used as a measure of implicit memory performance.

Orthographic and phonological word decoding. Surface type and Phonological type subgroups were identified by examining the discrepancy between orthographic and phonological word decoding skills in individual subjects. These skills were assessed by two computerised tests designed after Olson, Kliegl, Davidson, and Foltz (1985). Orthographic word decoding skill was assessed by having the children read 45 word pairs on the computer screen, one pair at the time. The children were asked to identify which word was correctly spelled as quickly and accurately as possible and press either the response button to the left or the one to the right on the keyboard. The

word pairs were constructed so that only one word was correctly spelled but the two words had an identical phonological code, that is, the nonword had the same Swedish pronunciation as the real word. Since both words sounded like a real word the subjects had to rely on their memory for word-specific orthographical patterns to make a correct response.

The phonological word decoding test consisted of an additional 45 word pairs. Here, both words were pronounceable nonwords but only one of the words sounded like a real Swedish word. The task was to identify the word that sounded like a real word as quickly and accurately as possible and press the corresponding response button. In this task all words were nonwords which could not be identified by relying on orthographic word decoding and the subjects had to employ phonological word decoding to be successful.

The computer registered response times and the number of correct responses in both word decoding tests. The number of correct responses per minute were used as measures of orthographic and phonological word decoding ability. Half of the subjects started with the orthographic decoding test and half started with the phonological decoding test.

Verbal fluency. Finally, the children received two different verbal fluency tests. In a semantic verbal fluency task the children were asked to generate 10 members of a particular semantic category as quickly as possible. The task was performed twice with two different semantic categories (animals and edible things) and the sum of the two times was used as a measure of semantic verbal fluency.

In another, phonologically-based verbal fluency task, the children were asked to generate 10 Swedish words which began with a particular phoneme as quickly as possible. This task was also performed twice with two different phonemes (*s* and *t*), and the sum of the two times was used as a measure of Phonological verbal fluency. Half of the subjects first completed the

semantic verbal fluency task and the other half started with the phonologically based task.

RESULTS

Initial group comparisons

First, 12 separate one-way ANOVAs with group (reading disabled children, reading-level controls, and age matched controls) as a between-subjects factor were performed on the cognitive measures included in the study (see Table 1). The Tukey-Kramer procedure, adjusting for unequal sample size, was used for all post hoc comparisons. The large number of analyses means that the results should be interpreted with caution.

Insert TABLE 1 about here

ANOVAs showed main effects for group on all measures, except for the two implicit memory tests (all other $ps<.05$). The Tukey-Kramer post-hoc tests revealed that the age matched controls outperformed the other two groups on measures of reading ability, orthographic decoding, phonological decoding, visual and auditory explicit memory, arithmetic, and semantic verbal fluency (all $ps<.05$). The age matched controls also outperformed the reading disabled children on listening comprehension ($p<.05$). No other statistically significant differences were found. These results established that the RD children were poor readers compared to age matched controls and that they were matched with RL controls on reading ability and approximately matched also on orthographic and phonological word decoding skill. A re-analysis of data from a previous study (Samuelsson et al., 2000) also revealed very high correlations between the measure of reading ability employed in the present study and a general word recognition test (i.e., lexical decision, $r=.86$ for accuracy and $r=.80$ for speed). Thus, RD children and RL controls should be approximately matched also

on general word recognition ability. It should also be noted that the RD children performed below the age matched controls on most measures and that no statistically significant differences were found between reading disabled and RL matched subjects.

Identifying the subgroups

Subgroups of reading disabled children were then identified using the regression method introduced by Castles and Coltheart (1993). Instead of using the exception word/pseudoword contrast in the regression analyses, the phonological and orthographic word decoding tests were used, mainly due to the relatively shallow orthography of Swedish compared to English. In a previous study (Samuelsson et al., 2000) the two alternative sets of tests resulted in very similar classifications into subgroups. Thus, orthographic and phonological word decoding was plotted against each other in two regression analyses with either orthographic or phonological decoding as the predictor variable. First, this was performed on the age matched controls data. The resulting regression lines with the 95% confidence intervals were then superimposed on the corresponding scatter plot of the RD children. Phonological dyslexics were defined as those subjects who fell below the 95% confidence interval on phonological, relative to orthographic, decoding when orthographic decoding was the predictor. Correspondingly, surface dyslexics were defined as those who fell below the 95% confidence interval on orthographic decoding using phonological decoding as the predictor. Mixed subjects consisted of subjects who did not fulfil either of these criteria. Contrary to previous regression based studies (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997) no subjects fell below the confidence interval on both scatter plots, neither when the regression lines were supplied by age matched controls, nor when supplied by RL matched controls. Thus, all mixed subjects were above the confidence interval on both scatter plots in the present study.

When age matched controls supplied the regression lines, 11 phonological type, 30 surface type and 12 mixed type of reading disabilities were identified (see Figures 1 and 2). Thus, when compared to an age matched control group, the majority (57%) of the reading disabled children were categorised as surface type.

Insert FIGURES 1 and 2 about here

However, when the regression lines were collected from the reading-level matched controls another picture emerged (see Figures 3 and 4). Using RL controls, the number of phonological type subjects increased to 18, whereas the number of surface type subjects decreased to 10. Twenty-five subjects were now categorised as mixed type of reading disability.

Insert FIGURES 3 and 4 about here

The results of these subgrouping procedures are in line with previous studies showing that the choice of comparison group is critical for the results of such a subgrouping procedure and that the number of surface dyslexics is reduced when comparisons are made with reading-level matched controls (Manis et al., 1996; Stanovich et al., 1997). Since there are strong arguments that RL matched controls are a better benchmark for identifying subgroups of poor readers than age matched controls (Bryant & Impey, 1986; Manis et al., 1996; Stanovich et al., 1997), the following analyses are based on the subgroups that resulted from the RL matched comparisons.

Cognitive measures

Seven separate one-way ANOVAs with group (phonological type, surface type, mixed type, and reading-level matched controls) as a between-subjects

factor were performed on the measures of reading skills, semantic skills and phonological verbal fluency included in the study (see Table 2).

Insert TABLE 2 about here

As predicted, statistically significant main effects for group were found on the two defining measures of orthographic word decoding, $F(3, 75)=5.17$, $p<.01$, and phonological word decoding, $F(3, 75)=5.07$, $p<.01$. The Tukey-Kramer procedure showed that the surface subgroup performed significantly below both the mixed and the phonological subgroup on orthographic decoding, with both $ps<.05$. The phonological subgroup performed significantly below the mixed subgroup on phonological decoding, $p<.05$. Another ANOVA showed a main effect for group on listening comprehension $F(3, 75)=3.47$, $p<.05$. The Tukey-Kramer procedure revealed that surface type children performed significantly below both phonological type subjects and RL matched controls, with both $ps<.05$. There was also a statistically significant main effect for group on arithmetic, $F(3, 74)=3.38$, $p<.05$. Surface type subjects performed significantly below mixed type subjects, $p<.05$. Finally, an ANOVA showed a tendency for a main effect for group on semantic verbal fluency, $F(3, 75)=2.59$, $p=.06$. Also note that there were no statistically significant main effects for group on the measures of reading ability and phonological verbal fluency (both $ps>.05$).

Explicit and implicit memory was then analysed by 8 separate one-way ANOVAs with group as a between-subjects factor (see Table 3).

Insert TABLE 3 about here

There was a main effect for group on auditory explicit memory, $F(3, 75)=3.64$, $p<.05$. The Tukey-Kramer procedure revealed that surface type children

performed significantly below mixed type children, $p<.05$. There was also a statistically significant main effect for group on visual implicit memory for low frequency words, $F(3, 75)=3.58$, $p<.05$. The Tukey-Kramer comparisons revealed that surface type subjects showed less priming than mixed type subjects, $p<.05$. There were no statistically significant main effects for group on visual explicit memory, visual implicit memory for high frequency words and auditory implicit memory, all $ps>.05$.

Print exposure

Print exposure was then examined based on the questionnaire data. Since comparisons were made between mo than two independent groups and data was on ordinal scales, the Kruskal-Wallis one-way ANOVA was used. The Kruskal-Wallis test showed that there was a statistically significant difference between the four groups (phonological type, surface type, mixed type, and RL matched controls) on the question "Approximately how many books are there in your home?", *H corrected for ties* (3)=16.61, $p<.01$. Median values were "more than 200 books" for mixed type subjects and RL matched controls, "101-200 books" for phonological type subjects, and the median was between the two response alternatives "11-50 books" and "51-100 books" for surface type subjects. Multiple comparisons using the mean ranks (see Hollander & Wolfe, 1973, p. 124) revealed that surface type subjects reported statistically significantly less books at home than both mixed type subjects and RL matched controls (both $ps<.05$). Another Kruskal-Wallis test showed a statistically significant difference between the groups on the question "How often do you get homework assignments in reading?", *H corrected for ties* (3)=8.40, $p<.05$. Median values were "3 or 4 times a week" for phonological type subjects, "1 or 2 times a week" for mixed type subjects and RL matched controls, and was between the two response alternatives "Never" and "1 or 2 times a week" for surface type subjects. However, the multiple comparisons using the mean ranks all failed to reach significance

(all *ps*>.05). No statistically significant main effects for group were found on the questions how often the children read books for fun, how often they read cartoons, how often they read weekly magazines, how often they read newspapers, or how often they think they read compared to their friends (all *ps*>.05).

Correlations between word decoding skills and the other measures

Dichotomous classifications of children into subgroups do not acknowledge that orthographic and phonological word decoding are continuous variables. Therefore, correlations between the two word decoding skills and measures of cognitive abilities and print exposure were also examined, using the whole sample of reading disabled children. In order to obtain clean measures of orthographic and phonological word decoding, two new variables were created. First, orthographic decoding skill was regressed out of phonological decoding skill and the residual was saved, then the opposite regression was performed. Thus, orthographic skill was defined in relation to the level of phonological skill, and vice versa. The two new variables were then correlated with the cognitive measures presented in Table 1 and the print exposure data. The results revealed only one substantial correlation: between the new orthographic decoding variable and the question "How many books are there at your home?" (*Rho corrected for ties*=.51, $p<.001$). This result was in line with the finding that surface type children tended to report less books at their homes than the other groups. All other correlations were low to moderate (*r* and *Rho*<.33).

DISCUSSION

The initial group comparisons revealed that reading disabled children in our sample performed statistically significantly below age matched controls not only on measures of reading skills, but also on measures of explicit memory, listening comprehension, arithmetic, and semantic verbal fluency (see Fletcher et al., 1994; Stanovich, 1986; Wagner & Torgesen, 1987). On the

other hand, no statistically significant differences were found between RD children and RL matched controls (see Table 1). Thus, our sample of reading disabled children would not, as a group, satisfy a narrow definition of developmental dyslexia which would demand more specific deficits, restricted to reading skills and phonological processing. Our sample of RD children represented children who were receiving special instruction in reading and who read at the same level as children who were more than two years younger. In this respect, the sample reflects a high external validity. However, the lack of a specific phonological deficit compared to RL matched children should be acknowledged when comparing our results to previous regression based subgrouping studies (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997).

The present study replicates the findings of Manis et al., (1996) and Stanovich et al (1997) that the number of subjects identified as either phonological type or surface type are substantially affected by a change of comparison group from age matched controls to reading-level matched controls. The number of phonological type subjects increased from 11 to 18 whereas the number of surface type children decreased from 30 to 10. Compared to the results of the previous studies by Manis et al. (1996) and Stanovich et al. (1997), a greater percentage of subjects remained either phonological type or surface type when RL controls were used as a benchmark. However, the results of the present study replicate findings that the number of surface type subjects is significantly reduced when comparisons are made with RL matched controls. This indicates that the word decoding skills (i.e., relative performance on orthographic compared to phonological decoding) of the surface type of reading disability bear similarities to that of younger children. This, in itself, supports the hypothesis that the surface type of reading disability might be characterised as a general developmental delay, whereas the phonological type might be

characterised as true deviancy (Bryant & Impey, 1986; Manis et al., 1996; Plaut & Shallice, 1994; Stanovich et al., 1997).

In contrast to previous studies, in the present study the number of surface type subjects resulting from comparisons with the most relevant control group (i.e., RL matched controls) was still high enough to allow for statistical comparisons with the other two groups, phonological type and mixed type. Comparisons on the cognitive measures revealed that, in general, surface type subjects tended to perform below the other three groups. The results on auditory explicit memory, listening comprehension, arithmetic, and semantic verbal fluency (*ns*), indicated that surface type subjects had more severe semantic difficulties. These results support the hypothesis that the surface type of reading disability can be characterised as a general developmental delay rather than stemming from any specific cognitive deficit (Bryant & Impey, 1986; Manis et al., 1996; Plaut & Shallice, 1994; Samuelsson et al., in press; Seidenberg & McClelland, 1989; Stanovich et al., 1997). It is also possible that the initial sample of reading disabled children included a number of children with semantic deficits and general language comprehension problems. The results suggest that children with such global deficits tend to remain in the surface type category, also when RL controls supply the regression lines (see Manis et al., 1996).

Phonological type children, on the other hand, only showed a specific deficit in phonological word decoding compared to the other three groups. Contrary to our prediction, they did not perform significantly below the other groups on the measure of phonological verbal fluency. This result could be explained by the fact that this task is not strictly phonological but also includes a semantic component. The results of the auditory implicit memory test indicated that phonological type children may have relatively intact phonological representations of words in their auditory word form system. The difficulties in using the phonological word decoding strategy

might perhaps stem from difficulties in the active manipulation (blending) of phonemes in words rather than poor representations of the words themselves.

The mixed type subgroup in the present study tended to perform on par with, or slightly better than, the other three groups (see Tables 2 and 3). Here, it should be noted that the mixed subgroup consisted of children who did not fall below the confidence intervals on any of the two scatter plots. In the studies referred to previously, several of the dyslexic subjects fell significantly below the regression lines on both scatter plots: 5.7% in the study by Castles and Coltheart (1993), 9.8% in the study by Manis et al. (1996) and 27.9% in the study by Stanovich et al. (1997), when age matched controls supplied the regression lines. Stanovich et al. (1997) suggested that this difference might be due to the fact that their dyslexic children were younger, and that there is an increasing dissociation between lexical and sublexical processes with age in dyslexic children. Mean age of the reading disabled children in the present study, 134 months, was also significantly higher than the mean age of the dyslexics in the study by Stanovich et al. (1997), 107.5 months, but comparable to the studies by Castles and Coltheart (1993) and Manis et al. (1996), 138 and 149 months, respectively. Here, it should also be noted that the studies by Castles and Coltheart (1993) and Stanovich et al. (1997) used 90% confidence intervals, whereas the study by Manis et al. (1996) and the present study used 95% confidence intervals, significantly reducing the number of subjects falling below the confidence intervals on both scatter plots. Still, a substantial proportion of the RD children in the present study failed to show any discrepancy between their orthographic and phonological word decoding skills (23% of the RD children belonged to the mixed type when age matched controls supplied the regression lines and as many as 47% when supplied by RL controls). Mixed type subjects performed below age matched controls on most cognitive measures but their general

pattern of results was rather similar to that of younger, RL matched controls (see Tables, 1-3). This suggests that many of the reading disabled subjects, identified as mixed type when compared to RL matched controls, might be characterised by a general developmental delay.

The questionnaire data indicated that differences in print exposure might also be related to word decoding skills in RD children. A statistically significant difference between groups was found on the question "Approximately how many books are there in your home?". Surface type children tended to report fewer books at home than the other groups (significantly less than mixed type and RL controls but not compared to phonological type children). A highly significant correlation was also obtained between the reported number of books at home and the orthographic decoding variable. These results are in line with findings showing that home literacy environment can predict orthographic processing skill (Braten, Lie, Andreassen, & Olaussen, 1999) and early reading achievement (Leseman & de Jong, 1998; Sénéchal, Lefevre, Thomas, & Daley, 1998). Also, in the Swedish section of the IEA study of reading literacy (Taube, 1995) a positive correlation was found between the number of books reported at home and reading comprehension (r=.30 for the fourteen-year-olds). The finding that surface type children tended to report fewer books at home is in line with the hypothesis that this type of reading disability is characterised by a general delay rather than a specific cognitive deficit. If surface type children tend to come from poor home literacy environments, this might partly explain their delayed reading development (Stanovich et al., 1997). However, the questionnaire data should be interpreted with caution. In particular, there is a risk of confounding effects of social desirability when using self-reports. These effects would probably be more pronounced for children reporting less desirable answers, hence reducing differences between groups rather than enhancing them. Still, the

fact that no differences between subgroups were found on the questions concerning the current reading habits of the children and the risk of capitalizing on chance when performing several statistical tests suggest that the print exposure results should be regarded as preliminary findings. The possibility of limited print exposure in the surface type of reading disability needs to be examined in more detail in future studies.

The finding that surface type children show less visual priming for low frequency words than the other groups of children is also in line with the hypothesis that the surface type of reading disability might, to some extent, be explained by insufficient print exposure. Visual priming for low frequency words could be regarded as a measure of the strength of the orthographic representations for these words in the visual word form system. Limited print exposure during early reading development would be expected to have the most disturbing effects on low frequency words. It cannot be ruled out that there might also be some underlying cognitive deficits which prevent surface type children from forming adequate orthographic representations. (Samuelsson et al., in press; Samuelsson et al., 1998). However, if the visual word form system is impaired in the surface type of reading disability one would expect to find a reduced amount of visual priming for high frequency words as well as for low frequency words. Thus, the results of the present study rather suggest that the surface type of reading disability stems from a general developmental delay which might be associated with a less stimulating home environment (cf. Stanovich et al., 1997). As was noted in the Materials and procedure section, some variation in the amount of vocalisation of words were allowed in the study phase of the visual modality. Therefore, the results concerning explicit and implicit memory in the visual modality should be interpreted with caution. However, findings from memory research indicate that elaboration in the study phase only has limited effects on data-driven implicit memory

performance (Graf & Mandler, 1994; Jacoby & Dallas, 1981), and that there is limited transfer from one modality to the other (Graf, Shimamura, & Squire, 1985). Thus, possible group differences in the vocalisation of words in the study phase would not be expected to have pronounced effects on stem completion performance.

When discussing differences between subgroups it should be acknowledged that the regression-based subgrouping procedure is based on arbitrary cut-offs between groups. In order to further validate this particular procedure, future studies should assess the stability of the subgroups by repeating the measurements and regression analyses using the same group of RD children. The results of the present study suggest that both cognitive and environmental factors should be examined in the resulting subgroups.

Behavioural genetic studies might provide additional insights into the relative influence of genetic and environmental factors. In a recent study by Castles et al. (1999), reading deficits were found to be significantly heritable for both phonological and surface dyslexics but the genetic contribution to the reading deficits was much greater in phonological dyslexics. The results also suggested that there is a strong environmental contribution in surface dyslexia. Thus, these results provide additional evidence that the division of surface and phonological dyslexia is valid and might be helpful in suggesting relevant interventions.

Stanovich et al. (1997) hypothesised that phonological dyslexia will be more difficult to remediate than surface dyslexia, since phonological dyslexia seems to reflect true deviancy in terms of severe underlying phonological difficulties. This certainly seems a reasonable prediction based on previous research. However, it should be noted that relative strengths and weaknesses in terms of orthographic and phonological word decoding do not necessarily tell *how* a particular child is actually reading. In order to be able to suggest relevant and individually adapted interventions, it seems

important to examine not only possible discrepancies between orthographic and phonological word decoding skills, but also the relative reliance on the two word decoding strategies in text reading.

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TABLE 1. Mean scores for Reading disabled children (n=53), Reading-level matched controls (n=26), and Age matched controls (n=29), (standard deviations in parentheses).

	Reading disabled	RL matched controls	Age matched controls
Age	11.1 (0.7)	8.9 (0.3)	11.0 (0.7)
Reading ability (/33)	20.5 (5.1)	21.5 (7.6)	30.8 (2.2)
Orthographic decoding (correct words/minute)	13.5 (5.7)	11.8 (7.1)	30.3 (10.3)
Phonological decoding (correct words/minute)	7.7 (2.2)	8.0 (3.6)	13.4 (4.1)
Visual explicit memory (/32)	11.3 (4.2)	11.2 (3.1)	16.5 (3.1)
Auditory explicit memory (/32)	13.9 (3.7)	15.0 (3.3)	17.8 (3.0)
Visual implicit memory (%)[a]	22.6 (11.8)	20.8 (12.5)	27.6 (7.5)
Auditory implicit memory (%)[b]	17.5 (11.6)	13.7 (8.1)	18.2 (10.6)
Listening comprehension (/30)	26.1 (2.4)	26.8 (1.7)	27.5 (1.7)
Arithmetic skill	36.2 (11.1)	33.9 (9.1)	50.2 (13.5)
Semantic verbal fluency (speed in seconds)	39.9 (19.5)	36.8 (15.5)	25.6 (13.0)
Phonological verbal fluency (speed in seconds)	102.5 (49.9)	108.1 (51.1)	75.0 (54.2)

[a] Baseline performances, which have been subtracted from the raw scores on stem completion, were 18.8% for RD children, 18.8% for RL matched controls, and 25.6% for age matched controls.

[b] Baseline performances, which have been subtracted from the raw scores on word identification, were 30.1% for RD children, 29.0% for RL matched controls, and 32.4% for age matched controls.

TABLE 2. Reading skills, semantic measures and phonological fluency for Mixed type (n=25), Phonological type (n=18), Surface type (n=10), and Reading-level matched control subjects (n=26), (mean scores, standard deviations in parentheses).

	Mixed subgroup	Phonological subgroup	Surface subgroup	RL matched controls
Reading ability (/33)	20.8 (4.6)	21.2 (4.8)	18.9 (6.6)	21.5 (7.6)
Orthographic decoding (correct words/minute)	14.8 (5.3)	15.0 (5.5)	7.4 (1.1)	11.8 (7.1)
Phonological decoding (correct words/minute)	9.1 (2.2)	6.1 (1.4)	7.2 (1.2)	8.0 (3.6)
Listening comprehension (/30)	26.1 (1.9)	27.1 (1.6)	24.6 (3.9)	26.8 (1.7)
Arithmetic skill	39.3 (9.4)	36.6 (13.3)	27.9 (6.2)	33.9 (9.1)
Semantic verbal fluency (speed in seconds)	34.9 (14.3)	39.6 (21.1)	52.7 (23.6)	36.8 (15.5)
Phonological verbal fluency (speed in seconds)	94.0 (36.7)	117.5 (64.6)	97.0 (46.8)	108.1 (51.1)

TABLE 3. Explicit and implicit memory for Mixed type (n=25), Phonological type (n=18), Surface type (n=10), and Reading-level matched control subjects (n=26), (mean scores, standard deviations in parentheses).

	Mixed subgroup	Phonological subgroup	Surface subgroup	RL matched controls
Visual explicit memory (/32)	12.0 (4.8)	11.7 (4.1)	9.1 (2.0)	11.2 (3.1)
Auditory explicit memory (/32)	15.3 (3.6)	13.0 (3.7)	11.9 (2.1)	15.0 (3.3)
Visual implicit memory				
All words (%)	24.5 (12.3)	23.8 (11.2)	15.6 (10.0)	20.8 (12.5)
High frequency words (%)	24.7 (14.8)	27.0 (14.7)	23.6 (13.0)	22.1 (15.7)
Low frequency words (%)	24.3 (13.5)	20.6 (15.0)	7.7 (12.3)	19.5 (13.1)
Auditory implicit memory				
All words (%)	18.8 (12.8)	17.1 (9.8)	14.9 (12.5)	13.7 (8.1)
High frequency words (%)	16.9 (14.9)	14.0 (10.1)	13.3 (17.0)	7.7 (12.7)
Low frequency words (%)	20.7 (14.7)	20.3 (12.5)	16.6 (10.4)	19.6 (11.1)

Figure Caption

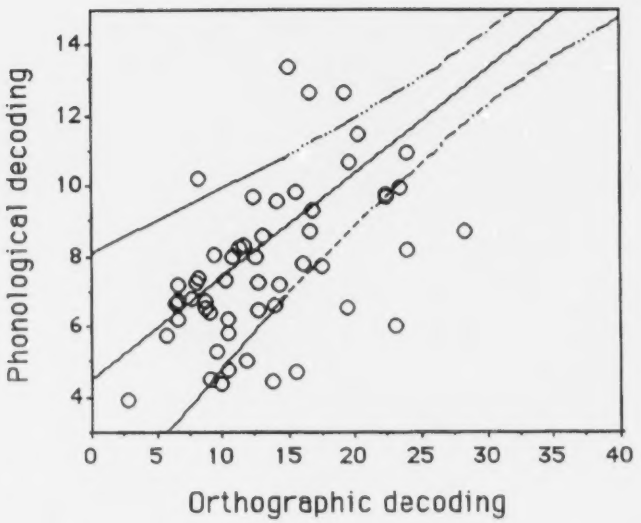
Figure 1. Phonological decoding skills plotted against orthographic decoding skills for reading disabled children, with the regression line and 90% confidence limit derived from age matched controls. Eleven phonological type children are defined below the 90% confidence limit.

Figure 2. Orthographic decoding skills plotted against phonological decoding skills for reading disabled children, with the regression line and 90% confidence limit derived from age matched controls. Thirty surface type children are defined below the 90% confidence limit.

Figure 3. Phonological decoding skills plotted against orthographic decoding skills for reading disabled children, with the regression line and 90% confidence limit derived from reading-level matched controls. Eighteen phonological type children are defined below the 90% confidence limit.

Figure 4. Orthographic decoding skills plotted against phonological decoding skills for reading disabled children, with the regression line and 90% confidence limit derived from reading-level matched controls. Ten surface type children are defined below the 90% confidence limit.

Figure 1


Phonological decoding
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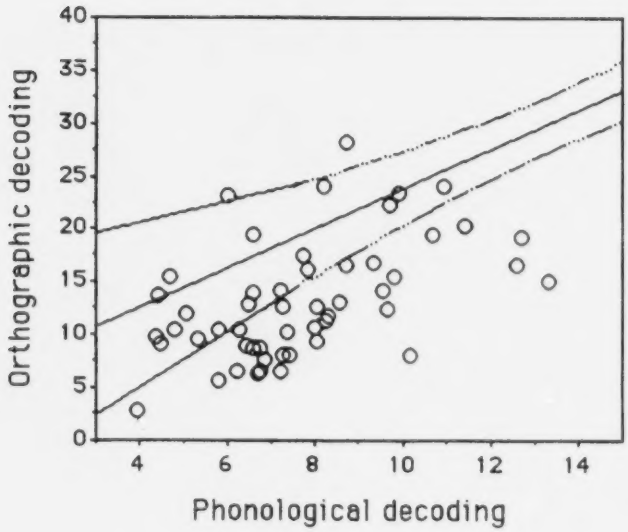
Orthographic decoding

Figure 2


Orthographic decoding
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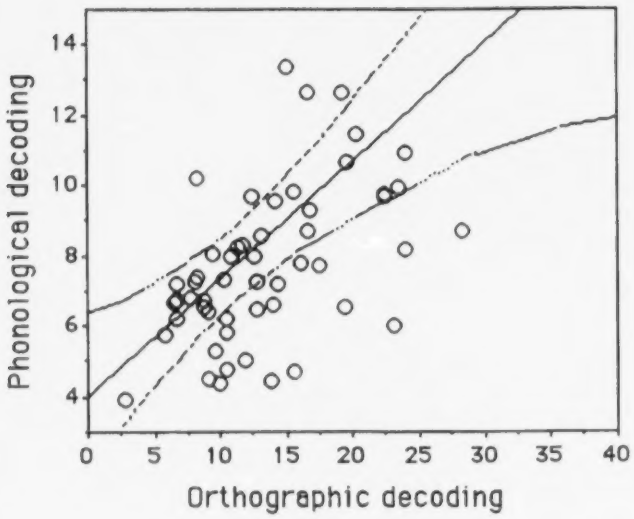
Phonological decoding

Figure 3


Phonological decoding
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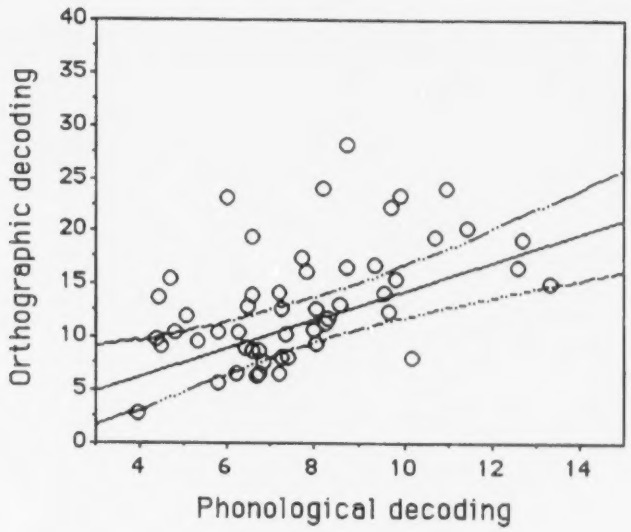
Orthographic decoding

Figure 4


Orthographic decoding
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Phonological decoding

Study V

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Why Do Some Resist Phonological Intervention? A Swedish longitudinal study of poor readers in Grade 4

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ABSTRACT *In a longitudinal intervention study, 33 Swedish poor readers in Grade 4 received phonological awareness instruction over 1 year. Three control groups were included in the study: Grade 4 controls, Grade 2 controls (both comparable in reading skill) and normal readers. The results showed that the phonological training group made the most progress in phonological awareness but did not improve their reading skills any more than the controls. However, a re-analysis of the results revealed important individual differences within the phonological training group. Some children improved their reading ability considerably, while others seemed resistant to the intervention. One critical difference between improved and resistant readers was identified. For the improved readers, both orthographic and phonological word decoding predicted text reading performance. For the resistant readers, only orthographic decoding skills predicted text reading before, during and after the intervention, in spite of a steady increase in phonological awareness.*

INTRODUCTION

There is now strong evidence for the critical role of phonology in learning to read (for a review see Share & Stanovich, 1995). It has been demonstrated that phonological awareness tasks, which measure the ability to explicitly reflect on the sound structure of words, are good predictors of early reading acquisition (for reviews see Wagner & Torgesen, 1987; Goswami & Bryant, 1990). Studies have also shown that dyslexic children perform below normal on various phonological tasks, suggesting that reading difficulties in developmental dyslexia are linked to an impairment in phonological processing (Snowling, 1981; Stanovich, 1988; Lundberg & Høien, 1989; Snowling & Hulme, 1989; Rack *et al.*, 1992; Tunmer & Hoover, 1993).

To obtain evidence for a causal relationship between phonological skills and reading skills, longitudinal intervention studies have been conducted. Positive results of phonological (or phoneme) awareness training for kindergarten and first grade children have been reported by several authors (Ball & Blachman, 1988, 1991; Lie, 1991; Torgesen *et al.*, 1992; Brady *et al.*, 1994; Lundberg *et al.*, 1988). Thus, there

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seems to be evidence for a causal relationship between phonological skills and reading ability. However, phonological awareness instruction combined with activities explicitly linking phonology and reading might be a more effective teaching method for young children (Bradley & Bryant, 1983; Cunningham, 1990; Hatcher *et al.*, 1994). For example, in the study by Hatcher *et al.* (1994), 7-year-old poor readers who only received phonological training made the most progress on phonological tasks, whereas children who received phonological training in combination with letter–sound 'linkage activities' and reading instruction made more progress in reading. However, the amount of progress in reading skills following a combination of phonological training and reading instruction was rather moderate and reported as significant only compared to the control group, not compared to the other teaching methods.

In all of the intervention studies mentioned above the children were quite young; in kindergarten or 7 years old at most. These children have not yet received much formal reading instruction and since their reading acquisition was in an early stage it might also be difficult to classify these children as either normal or poor readers. This means that previous interventions have not been specifically directed at older children where there are strong indications of lasting reading difficulties.

Another important question, as pointed out by Torgesen & Davis (1996), is that very little is known about variability among children receiving phonological awareness training. Average training effects might hide individual differences and might also reflect a 'hothouse effect' for children with no inherent difficulties in learning to read rather than improved reading skills for children who would experience reading difficulties later in school. We believe that instead of focusing only on *average improvements* following different teaching methods and, thus, emphasising which intervention seems to work for most children, intervention studies should also acknowledge individual differences within a group of children who are in need of remediation.

Grade 4 children (10–11 years old in Sweden) differ from younger children in at least three ways which could be critical for the effectiveness of any intervention. One obvious difference is that children in Grade 4 have received formal reading instruction for more than 3 years. Early reading instruction in Sweden emphasises knowledge about the letters of the alphabet (and the corresponding sounds) while strictly phonological training is relatively less frequent. A second difference is that children with lasting reading difficulties might suffer from phonological deficits to a greater extent than younger children without any apparent reading difficulties (Lundberg, 1984; Stanovich, 1986; Juel, 1988). Third, when children have been subject to formal reading instruction in school for some years, they might also have developed certain individual strategies when dealing with written language, such as more reliance on either the orthographic or the phonological strategy for word decoding (Share & Stanovich, 1995; Stanovich *et al.*, 1997; Samuelsson *et al.*, 1998). Individual differences in strategies for word decoding have not been examined in the intervention studies referred to previously but could clearly have implications for the effectiveness of phonological awareness training.

Most models of the acquisition of word identification skills suggest that both

phonological and orthographic information are involved in identifying words in printed form (Frith, 1985; Ehri, 1987, 1993; Ehri & Wilce, 1987). Phonological word decoding skill refers to an identification of words based on letter–sound conversion, whereas orthographic word decoding skill refers to the ability to recognise words directly, on a visual basis. The relative influence of each decoding skill in reading is assumed to change with age from a more phonological to a more orthographic reliance in word identification (Frith, 1985; Juel *et al.*, 1986; Ehri, 1987; Ehri & Wilce, 1987; Samuelsson *et al.*, 1996). Thus, the contribution of phonological skills gradually decreases with an increase in reading skill and poor readers normally rely on phonological information for word identification to a greater extent than do age-matched normal readers. However, progress in reading can be made by relying on visual strategies and some poor readers may learn to read by gradually increasing their 'sight vocabulary' of printed words, making very little use of phonological word decoding (Snowling & Hulme, 1989; Ehri, 1992, 1993). Thus, when studying the reading skills of children who have been subject to reading instruction in school for several years one would expect to find individual differences in word decoding strategies.

In the present study we will address two questions. First, is phonological awareness training effective for children with established reading difficulties? Second, can differences in word decoding strategies account for individual differences in the effectiveness of phonological awareness training?

METHOD

Participants

A total of 148 children participated in the study. The subjects were divided into four different groups: phonological training (33 subjects), Grade 4 controls (16 subjects), Grade 2 controls (16 subjects) and normal readers (83 subjects).

Fourteen special instruction teachers, from 14 different schools in Norrköping, Sweden, agreed to participate in the study. All 14 schools represented socio-economic middle class populations. In these schools, 49 children, who were native Swedish speakers, had already been assigned for special instruction in reading and writing in Grade 4. These children were 10–11 years old (in Grade 4) and had received formal reading instruction in school for 3.5 years when the first test session was conducted (in December 1994). Personal communication with teachers and special instruction teachers revealed that the children had continuously received training on the letters of the alphabet and their corresponding sounds in school. They had also received instruction in spelling and in text reading on numerous occasions. On the other hand, strictly phonological training, focusing directly on the sound structure of the language, had been very limited.

The 14 schools and the 14 corresponding teachers were then randomly assigned to either the experimental condition, phonological training, or the control condition, Grade 4 controls. To allow an examination of individual differences in the effectiveness of phonological intervention, twice as many children were assigned to the

experimental condition. Based on this prerequisite, nine schools (33 children) were assigned to the phonological training group and the remaining 16 subjects, from the other five schools, were assigned to the Grade 4 control condition. Thus, 33 children later received instruction according to our phonological training programme, from one of nine special instruction teachers, during their scheduled special instruction sessions. The 16 children in the Grade 4 control group received ordinary special instruction, from one of the other five special instruction teachers, during their scheduled special instruction sessions. Thus, the Grade 4 controls was not a control group in a strictly experimental sense because this group also received reading instruction (cf. Hatcher *et al.*, 1994). However, the Grade 4 controls might be regarded as a more ecologically valid group for comparison since these children reflected the reading instruction a poor reader in Grade 4 would normally receive in school. Also, ethical considerations made it impossible to include a group of poor readers in Grade 4 who would receive no training. Personal communication with the special instruction teachers during the experimenter's visits on the three test occasions revealed that the reading instruction given to the Grade 4 controls was not focused on phonological awareness alone but consisted of a variety of activities more directly related to reading and writing, such as reading aloud or silently and discussing stories, as well as direct instruction in Swedish spelling rules.

Two additional control groups were included in the study. Eighty-three children, from the same nine schools and classrooms as the phonological training group, were randomly selected as normal readers. Sixteen children in Grade 2, thus being 2 years younger than the other three groups, were randomly selected as reading skill-matched Grade 2 controls from another public school in the same district (Norrköping). Again, only native Swedish speakers were included in these two groups.

Because Sweden still has a relatively homogeneous school system and because several different schools were randomly assigned to either the experimental or the Grade 4 control groups, the separation of the groups was not likely to create any other critical differences between the conditions. In a field experiment like this, the experimentally ideal conditions cannot always be fully attained but this solution was considered to be the best one, given the practical considerations that had to be made.

Materials and Procedure

The phonological training programme. The intervention consisted of a phonological training programme focused on phonological awareness tasks (similar to the training programme developed by Lundberg *et al.*, 1988). Seven different types of phonological exercises were included in a booklet: rhymes, position analysis, subtraction and addition of sounds, segmentation, blending and accentuation (Gustafson & Samuelsson, 1998). In the rhyme section (six different exercises), the child was taught rigmaroles and songs, was asked to say which words rhymed in a string of words or was asked to complete sentences with a word that rhymed. The position analysis tasks (six exercises) were focused on the position of phonemes in words. In the

addition (six exercises) and subtraction (three exercises) sections, the child was instructed to add or subtract segments or phonemes in words. In the segmentation section (eight exercises), the child was asked to divide words into segments or phonemes or to compare the (phonological) length of words. In the blending tasks (four exercises), either the teacher sounded out phonemes which the child should try to put together into words or the child saw an object and was asked to say and connect the phonemes of the word representing that object. In the accentuation tasks (three exercises), finally, words or sentences were orally presented by the teacher with an unusual accentuation and the child was asked to report what was wrong or the child was instructed to produce words or sentences and vary the accentuation within them. In most cases the children responded individually, but especially in some rhyming tasks, the children responded in choral form in small groups. The instructions and responses were entirely oral.

The booklet was developed in cooperation with the nine special instruction teachers, who used it to teach the children in the phonological training group during the intervention. All nine teachers were experienced special instruction teachers. The teachers were instructed to use the training programme systematically, to include all seven types of phonological exercises and to record the time they spent on each type of exercise for every child. The times spent on each type of exercise were approximately the same (a total of about 120 minutes on each type), except for the accentuation tasks, which received less training time (a total of about 40 minutes). This was partly due to the fact that there were only three accentuation exercises in the booklet, but the accentuation tasks might also have been perceived as being difficult to administer or not as relevant as the other exercises by the teachers. The teachers were instructed not to include any visual letters in connection with the exercises, to make the training programme strictly phonological. The children received the training in small groups of between two and four children.

The first period of intervention lasted from February 1995 to May 1995 and the second from September 1995 to December 1995. The three month hiatus from the intervention was due to the summer vacation, which in Sweden lasts from early June to mid August. This meant that all children made a transition from one grade to the next after the summer vacation. Thus, during the second period of intervention the groups phonological training, Grade 4 controls and normal readers were actually in Grade 5 and the group Grade 2 controls were actually in Grade 3. However, in no case did this transition lead to a change of school, classroom teacher or special instruction teacher.

With a few exceptions, the nine special instruction teachers assigned to the phonological training group met the children twice a week. This was also true for the five teachers assigned to the Grade 4 controls. Thus, the phonological training group and the Grade 4 controls received an equal total amount of special instruction in reading during the intervention (a total of approximately 40 sessions). The phonological training group received 20 minutes of instruction according to the phonological training programme in each session. Since the group Grade 4 controls received special instruction, they also received some phonological awareness training, but not according to our training programme. The phonological training group received

substantially more instruction in phonological awareness during the intervention than the Grade 4 controls (m = 762 versus 252 minutes). Furthermore, the minutes reported for the Grade 4 controls included activities which were not strictly phonological, i.e. phonological activities employed in combination with other reading and writing activities. Thus, the phonological training group received significantly more phonological awareness training, were exposed to a more comprehensive set of strictly phonological exercises and received the training in a more systematic manner compared with the Grade 4 controls.

Reading ability. Two separate tests, both measuring text reading performance and reading comprehension, were included in the study. In the first reading test (Malmquist, 1977) the children were instructed to read a short story (600 words in length) as accurately and quickly as they could. In the text there were 20 sentences which were incomplete, such that one word was missing and replaced by a parenthesis with three alternative single words. The children were instructed to select one out of the three alternatives that would complete the sentence in an appropriate way, every time they reached a parenthesis in the text. The children were allowed to work with the text for 6 minutes.

In the second reading test (Malmquist, 1977) the children were asked to read 12 short stories (20–150 words in length) as fast and accurately as possible and to answer easy multiple choice questions related to each story. The total number of multiple choice questions was 33 and the children were allowed 8 minutes to complete the test. The time limits of the two reading tests were set so that it would be difficult to read and answer all questions correctly, in order to avoid ceiling effects. The total number of correct responses from both reading tests (i.e. a maximum of 20 + 33 correct responses) was then used as an index of text reading performance. The reason for adding the results of the two different reading tests was to obtain a more reliable and valid measure of reading ability, which constitutes the crucial dependent variable in the study. The two tests were quite similar and the obtained correlations between the two tests for all subjects in the present study (n = 148) were r = 0.91 on the first test session, r = 0.91 on the second and r = 0.92 on the third, indicating that the two text reading tests did measure the same construct.

Word decoding skills. Two tests designed after Olson *et al.* (1985) were used in order to gain more specific knowledge concerning the orthographic and the phonological word decoding skills of the children, before, during and after the period of intervention. In the test measuring the ability to use the orthographic strategy, the subjects were presented with a list of 119 word pairs in Swedish, which had visual similarities and identical pronunciation (i.e. *hej* and *häj*; hello in English) on a piece of paper, one of the words being a real word (*hej*) and the other being a non-word. The subjects should identify, as quickly as possible, which word was a real word, i.e. which one had the correct spelling. The number of correct words chosen in 2 minutes was taken as a measure of the subject's orthographic reading ability.

In the phonological word decoding test (cf. Olson *et al.*, 1985) a list of 80 word

pairs was again presented to the subjects. This time none of the words were real words, but one of the words sounded like a real Swedish word if it was spoken aloud (i.e. *kjur* and *sorf*, where *kjur* sounds like the Swedish word *tjur*, bull in English). The subjects were requested to identify as quickly as possible which word sounded like a real word and the number of correct words chosen in 2 minutes was taken as a measure of their phonological reading ability.

The large number of word pairs in the orthographic and phonological word decoding tests made it impossible to complete all of them in 2 minutes.

Phonological awareness. We selected a sub-test from a Swedish standard test of phonological awareness; UMESOL: Segment Subtraction (Taube *et al.*, 1984). The task here was to decide which segment of a word had been removed from an original Swedish word (i.e. 'What has been removed from the word *krokodil* if only *kroko* remains?'). The maximum score was 15. Compared with the other sub-tests in UMESOL, Segment Subtraction is the most difficult and sensitive phonological awareness task, hence reducing ceiling effects.

Verbal fluency. Here, the subjects were instructed to verbally report as many members of a semantic category as possible in 30 seconds. Two semantic categories (birds and vegetables) were chosen by the experimenters and the sum of correct members from these categories was taken as a measure of verbal fluency. This measure was used to control for potential initial differences in semantic memory.

Visual perception. A sub-test of TVPS-UL (Gardner, 1992), named Visual–Spatial Relationships, was used to obtain a measure of the children's visual perception. The task was to tell which out of five otherwise identical figures was turned in another direction. The figures consisted of geometrical shapes (e.g. lines, squares or circles) in different combinations. Sixteen different sets of figures were presented and after each presentation the subject was asked to verbally report which figure was turned in another direction. Accordingly, the maximum score on this test was 16. In this task, which was used to control for potential initial differences in visual perception, the memory component was minimal.

Test administration. The tests were administered in the same order for all children. First, the two word decoding tests, followed by the two reading tests were administered to groups consisting of approximately six children. Thereafter, the tests measuring visual perception, verbal fluency and phonological awareness were performed individually. The total time needed to complete the test battery was approximately 50 minutes. All children were given these tests on three different occasions, except for the verbal fluency and visual perception tests, which were only included in the first test session. The initial test took place in December 1994, the second in May 1995 and the third in December 1995. To enhance the reliability of the study, the same experimenter (Stefan Gustafson) administered all the tests to all subjects. Each of the three test occasions required a total time of approximately 3 weeks. The experimenter therefore visited the different schools in approximately the same order on each test occasion.

RESULTS AND DISCUSSION

Visual Perception and Semantic Memory

An ANOVA showed that there was a main effect of group on visual perception in the first test session [$F(3,144) = 5.23$, $MSE = 2.89$, $p < 0.01$]. This was partly due to a better performance for the normal readers ($m = 14.8$) than for the other three groups. When the normal readers were removed and the ANOVA was repeated with the groups phonological training ($m = 13.8$), Grade 4 controls ($m = 14.6$) and Grade 2 controls ($m = 13.4$) no statistically significant main effect was found [$F(2,62) = 1.54$, $p > 0.05$]. Another ANOVA revealed a statistically significant main effect of group on verbal fluency [$F(3,144) = 6.37$, $MSE = 10.77$, $p < 0.01$]. This was also partly due to a better performance of the normal readers ($m = 11.7$) than for the other groups. Again, when the normal readers were removed and the ANOVA was repeated with the groups phonological training ($m = 10.2$), Grade 4 controls ($m = 9.5$) and Grade 2 controls ($m = 8.2$) no statistically significant main effect was found [$F(2,62) = 1.57$, $MSE = 12.43$, $p > 0.05$]. Thus, when the normal readers were removed from the analysis the other three groups (phonological training, Grade 4 controls and Grade 2 controls) obtained equivalent results both on a lower level test (visual perception) and a higher level test (verbal fluency). This is important to establish because visual perception and semantic memory capacity are factors that might hinder the acquisition of reading skills (Goulandris *et al.*, 1998; Oakhill & Garnham, 1988; Stein, 1996; Stothard & Hulme, 1996).

Initial Scores in Phonological Awareness, Reading Ability and Word Decoding Skills

The general design used to evaluate the intervention was a split-plot factorial design with group (4 levels) as a between-subjects factor and test session (3 levels) as a within-subjects factor. We used separate ANOVA with repeated measures to analyse changes in phonological awareness, reading ability, orthographic decoding and phonological decoding across groups and test sessions (see Table I).

Four separate one-way ANOVAs with group as a between-subjects factor at the first test session (i.e. one ANOVA for each task at test session 1) showed main effects (all $F > 10.0$, $p < 0.001$) for group. Planned comparisons revealed that the normal readers initially out-performed the other three groups on all four tests (all $p < 0.01$). On the other hand, when the normal readers were excluded from the analyses there were no statistically significant differences between the phonological training group, Grade 2 controls and Grade 4 controls on either task (all $F < 2.20$, $p > 0.05$). This confirms that our groups of poor readers from Grade 4 were initially comparable on all tasks prior to the intervention (see Table I). This also confirms that the Grade 2 controls constitute a reading-matched group when compared with poor readers in Grade 4. Based on these findings, we decided to exclude the group of normal readers from the subsequent analysis and, thus, a 3×3 split-plot factorial design was used to study longitudinal changes in reading ability, word decoding skills, and phonological awareness for the three remaining groups.

TABLE I. Reading skill, orthographic and phonological decoding skills and phonological awareness before, during and after the intervention for the groups phonological training ($n = 33$), Grade 4 controls ($n = 16$), Grade 2 controls ($n = 16$) and normal readers ($n = 83$) (mean scores, standard deviations in parentheses)

	Phonological training	Grade 4 controls	Grade 2 controls	Normal readers
Test session 1, December 1994				
Reading index	20.6 (8.3)	21.5 (5.9)	21.4 (12.4)	43.3 (9.0)
Orthographic decoding	9.1 (8.7)	8.1 (7.4)	8.0 (7.2)	29.3 (13.4)
Phonological decoding	11.2 (5.8)	11.6 (4.3)	12.6 (6.8)	23.7 (9.8)
Phonological awareness	6.7 (3.0)	8.2 (2.3)	7.9 (3.0)	10.0 (2.3)
Test session 2, May 1995				
Reading index	27.0 (10.0)	28.0 (8.5)	28.8 (13.0)	47.0 (6.6)
Orthographic decoding	16.1 (9.9)	12.5 (9.5)	14.1 (12.0)	38.9 (16.6)
Phonological decoding	13.8 (6.7)	15.1 (7.8)	16.1 (9.5)	29.1 (10.4)
Phonological awareness	8.7 (2.8)	8.5 (2.7)	8.6 (3.5)	10.4 (2.4)
Test session 3, December 1995				
Reading index	31.8 (10.6)	30.8 (8.9)	37.3 (12.0)	48.8 (5.7)
Orthographic decoding	19.8 (13.5)	20.2 (11.8)	23.4 (13.4)	46.8 (16.9)
Phonological decoding	14.9 (7.8)	16.9 (6.3)	23.4 (9.4)	33.9 (10.8)
Phonological awareness	9.9 (2.3)	9.2 (2.8)	8.7 (3.2)	11.0 (2.2)

Effects of the Intervention

Phonological awareness. Results of the analysis for phonological awareness revealed a statistically significant main effect for test session [$F(2,124) = 14.95$, $MSE = 2.81$, $p < 0.001$], suggesting that all three groups improved their phonological awareness regardless of whether they had received training or not (see Table I). There was no main effect of group [$F(2,62) = 1.57$, $p > 0.05$]. However, there was a statistically significant interaction between group and test session [$F(4,124) = 4.15$, $MSE = 2.81$, $p < 0.01$]. The mean score in phonological awareness for the phonological training group was improved by 3.24 points (or 48%) between December 1994 and December 1995. The improvement for the Grade 2 controls was 0.8 points (or 10%) and 1 point (or 12%) for the Grade 4 controls during the same period of time. These differences between groups were confirmed by planned comparisons (to adjust for unequal numbers between the groups we used df = 16). Thus, the improvement in phonological awareness shown by the phonological training group was statistically significantly higher than for the Grade 2 controls [$t(16) = 2.77$, $p < 0.05$] and Grade 4 controls [$t(16) = 2.56$, $p < 0.05$].

Reading ability. Analysis of the results for reading ability showed that all three groups improved their reading ability between December 1994 and December 1995 [$F(2,124) = 126.19$, $MSE = 16.79$, $p < 0.001$]. There was no statistically significant main effect for group [$F(2,62) = 0.48$, $p > 0.05$]. However, the interaction between group and test session was statistically significant [$F(4,124) = 3.25$, $MSE = 16.79$, $p < 0.05$], suggesting that the Grade 2 controls enhanced their reading ability more than the other two groups. Two-tailed planned comparisons confirmed that Grade 2 controls improved their reading ability more than the

phonological training group [$t(16) = 2.14$, $p = 0.05$] and Grade 4 controls [$t(16) = 2.97$, $p < 0.01$]. These results suggest that the improvement in phonological awareness displayed by the phonological training group was not generalised to their reading ability. In fact, the progress in reading ability was similar for the phonological group and the Grade 4 controls.

Orthographic decoding. Analysis of variance for orthographic decoding skills revealed only a main effect for test session [$F(2,124) = 77.97$, $MSE = 29.49$, $p < 0.001$]. There was no statistically significant main effect for group [$F(2,64) = 0.19$, $p > 0.05$] nor any statistically significant interaction between group and test session [$F(4,124) = 1.90$, $p > 0.05$]. There was a progress in orthographic decoding skills over time for all three groups and this improvement was rather similar in the three groups (i.e. 10.6, 12.2 and 15.4 for the phonological training group, Grade 4 controls and Grade 2 controls, respectively).

Phonological decoding. Finally, analysis of the results for phonological decoding showed an improvement in phonological decoding skills for all three groups over time [$F(2,124) = 35.58$, $MSE = 17.77$, $p < 0.001$]. There was no main effect for group [$F(2,64 = 2.27$, $p > 0.05$]. However, there was a statistically significant interaction between test session and group, indicating that the Grade 2 controls enhanced their phonological decoding skills more than the other two groups [$F(4,124) = 4.61$, $MSE = 17.77$, $p < 0.01$]. Two-tailed planned comparisons confirmed that Grade 2 controls increased their phonological coding skills more than the phonological training group [$t(16) = 3.08$, $p < 0.01$] and Grade 4 controls [$t(16) = 2.38$, $p < 0.05$].

Thus, the results presented in Table I indicate that the three groups were comparable on all four measures in test session 1. Furthermore, the intervention was successful only in the sense that the phonological training group improved their phonological awareness more than the other two groups. Instead, statistically significant interactions between test session and group clearly indicate that the Grade 2 controls increased their reading ability and phonological decoding skills more than the other two groups and that the phonological training group showed the same progress in reading ability and word decoding skills as the Grade 4 controls. These findings suggest that there is no guarantee that an improvement in phonological awareness is sufficient to improve reading ability, at least not for upper primary poor readers.

An Individual Difference Perspective: why do some resist?

It is important to note that mean scores of groups might hide substantial individual differences within the groups. The key question here is what differentiates between poor readers who benefit from phonological awareness instruction and those who do not benefit.

We divided the 33 children in the phonological group into two new groups. The 17 children who showed the most improvement in reading ability were named improved readers and the 16 children who showed the least improvement were named resistant readers. The division was based on the Reading Index scores in test session 3 minus the Reading Index scores in the first test session. It should be noted that the division of the phonological group into improved and resistant readers does not necessarily imply that they constitute discretely defined subgroups. Recent evidence from epidemiological studies support a normal distributional model of reading disability (Shaywitz *et al.*, 1996). Thus, different reading abilities, including phonological and orthographic word decoding skills, can be assumed to be distributed in a statistically normal way along a continuous dimension.

However, when the individual improvements in reading ability were specifically examined, a clear difference was found between the expected distribution of improvements revealed by the Grade 4 controls and the distribution obtained for the phonological training group.

As can be seen in Figure 1, 25% of the Grade 4 controls (four children) improved their reading ability by 0–7 points, 69% (11 children) gained 8–14 points and only one child (6%) gained 15–22 points. The corresponding numbers for the phonological training group was 37, 30 and 33%, respectively. Thus, whereas the majority of Grade 4 children (69%) showed an intermediate increase of 8–14 points, suggesting a normal distribution of their improvements, 70% of the children in the phonological training group were either in the lower tail or in the higher tail of the distribution, $\chi^2(2) = 7.39$, $p < 0.05$. In fact, the 10 children who showed the most improvement in reading ability all belonged to the phonological training group. Thus, the variation among children in terms of improvement in their reading ability did seem to be related to the nature of the treatment. This finding, in combination with the improvement in phonological awareness displayed by the phonological training group, also shows that there was a specific effect of the systematic and comprehensive training programme they received, compared with the Grade 4 controls who had received ordinary special instruction not focused on phonological awareness training.

The improved and resistant readers had received an almost equal amount of phonological awareness training (m = 780 versus 743 minutes). Mean performances on the tests measuring reading ability, orthographic and phonological decoding skills and phonological awareness in test sessions 1–3 are presented in Table II for improved readers, resistant readers, Grade 4 controls and Grade 2 controls.

The design used to study differences between improved and resistant readers was a split-plot factorial design with group (improved, resistant, Grade 2 controls and Grade 4 controls) as a between-subjects factor and test session (3 levels) as a within-subjects factor. Again, we used separate analyses of variance with repeated measures to analyse changes in reading ability, orthographic decoding, phonological decoding and phonological awareness across groups and test sessions.

Analysis for reading ability revealed a main effect for test session [$F(2,120) = 168.54$, $MSE = 13.36$, $p < 0.001$] and a statistically significant interaction between test session and group [$F(6,120) = 8.36$, $MSE = 13.36$, $p < 0.001$].

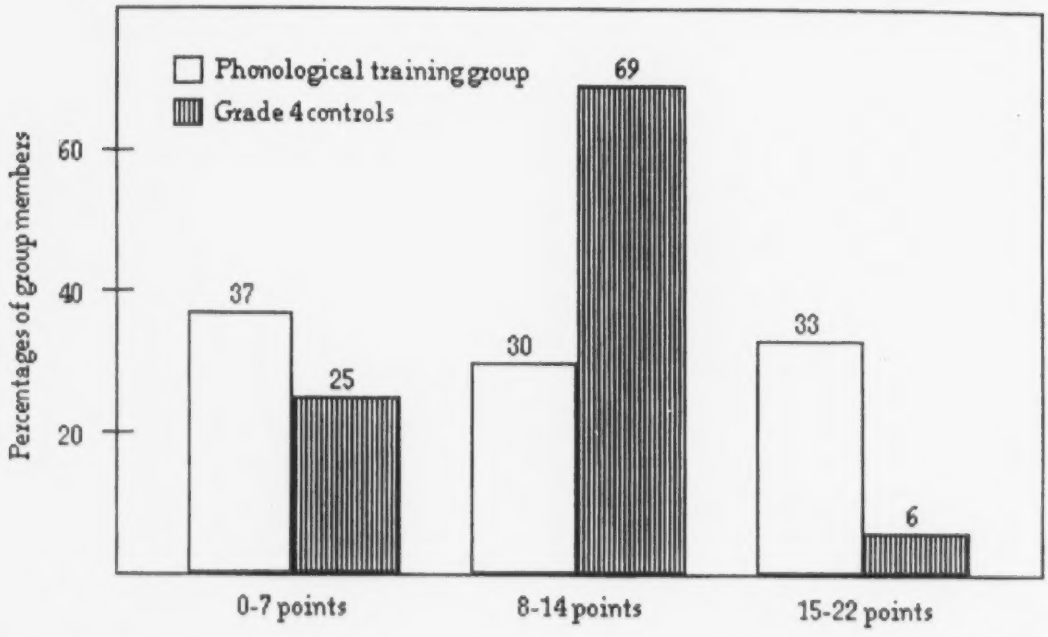

FIG. 1. The distribution of improvement in reading ability between December 1994 and December 1995 for the phonological training group ($n = 33$) and Grade 4 controls ($n = 16$).

There was no main effect for group [$F(3,60) = 1.00$, $p > 0.05$]. Two-tailed planned comparisons revealed that the improvement in reading ability for the improved readers was greater than for Grade 4 controls [$t(16) = 3.54$, $p < 0.01$] and for

TABLE II. Reading skill, orthographic and phonological decoding skills and phonological awareness before, during and after the intervention for improved readers ($n = 17$), resistant readers ($n = 16$), Grade 4 controls ($n = 16$) and Grade 2 controls ($n = 16$) (mean scores, standard deviations in parentheses)

	Improved readers	Resistant readers	Grade 4 controls	Grade 2 controls
Test session 1, December 1994				
Reading index	20.8 (8.2)	20.5 (8.6)	21.5 (5.9)	21.4 (12.4)
Orthographic decoding	10.4 (7.4)	7.8 (9.9)	8.1 (7.4)	8.0 (7.2)
Phonological decoding	10.9 (5.4)	11.5 (6.3)	11.6 (4.3)	12.6 (6.8)
Phonological awareness	7.6 (2.6)	5.7 (3.1)	8.2 (2.3)	7.9 (3.0)
Test session 2, May 1995				
Reading index	28.7 (10.4)	25.2 (9.8)	28.0 (8.5)	28.8 (13.0)
Orthographic decoding	16.9 (8.8)	15.2 (11.2)	12.5 (9.5)	14.1 (12.0)
Phonological decoding	14.8 (7.0)	12.8 (6.5)	15.1 (7.8)	16.1 (9.5)
Phonological awareness	9.2 (3.0)	8.1 (2.5)	8.5 (2.7)	8.6 (3.5)
Test session 3, December 1995				
Reading index	36.8 (9.5)	26.3 (9.0)	30.8 (8.9)	37.3 (12.0)
Orthographic decoding	22.1 (13.4)	17.2 (13.6)	20.2 (11.8)	23.4 (13.4)
Phonological decoding	15.2 (7.7)	14.5 (8.2)	16.9 (6.3)	23.4 (9.4)
Phonological awareness	10.1 (2.9)	9.8 (1.5)	9.2 (2.8)	8.7 (3.2)

resistant readers [$t(16) = 5.33$, $p < 0.01$]. Moreover, the increase in reading ability for improved readers was almost identical to the improvement made by Grade 2 controls (16.0 versus 15.9 points in reading ability). These findings are, so far, trivial because the subdivision into improved and resistant readers was based on the improvement in reading ability. However, it should be noted that improved readers made the same progress in reading as the Grade 2 controls.

The analysis for orthographic decoding only showed a main effect for test session [$F(2,120) = 74.61$, $MSE = 31.61$, $p < 0.001$]. There was no main effect for group [$F = (3,60) = .348$, $p > 0.05$] and no statistically significant interaction [$F(6,120) = 1.49$, $p > 0.05$].

The analysis for phonological decoding revealed a main effect for test session [$F(2,120) = 28.81$, $MSE = 18.49$, $p < 0.001$] and a statistically significant interaction between test session and group [$F(6,120) = 3.29$, $MSE = 18.49$, $p < 0.01$]. There was no main effect for group [$F(3,60) = 1.52$, $p > 0.05$]. Two-tailed planned comparisons showed that the Grade 2 controls improved their phonological decoding skills more than the other three groups (all $p < 0.05$).

Results of the analysis for phonological awareness also revealed a main effect for test session [$F(2,120) = 26.06$, $MSE = 2.77$, $p < 0.001$], suggesting an increase in phonological awareness across groups. The crucial interaction between test session and group was also statistically significant [$F(6,120) = 3.44$, $MSE = 2,77$, $p < 0.01$], while there was no main effect for group [$F(3,60) = 0.579$, $p > 0.05$]. An examination of Table II shows that improved and resistant readers increased their phonological awareness more than the other two groups (2.5 and 4.0 points, respectively, compared with 0.8 for Grade 2 controls and 1.0 for Grade 4 controls) and resistant readers seemed to perform lower on phonological awareness compared with the other three groups before the intervention. One-tailed planned comparisons revealed that the increase in phonological awareness for resistant readers was statistically significant compared with Grade 2 controls [$t(16) = 3.79$, $p < 0.001$] and Grade 4 controls [$t(16) = 3.57$, $p < 0.01$]. One-tailed planned comparisons also revealed a statistically significant increase in phonological awareness for improved readers compared to Grade 2 controls [$t(16) = 1.97$, $p < 0.05$] and Grade 4 controls [$t(16) = 1.76$, $p < 0.05$]. However, there was no statistically significant difference between resistant and improved readers in the amount of increase in phonological awareness [$t(16) = 1.57$, $p > 0.05$]. Two-tailed planned comparisons also showed that, in the first test session, the resistant readers performed below both the Grade 4 controls [$t(90) = 2.35$, $p < 0.05$] and the Grade 2 controls [$t(90) = 2.22$, $p < 0.05$] on the phonological awareness test. Finally, the initial difference in phonological awareness between resistant and improved readers just failed to reach statistical significance [$t(90) = 1.93$, $p = 0.06$].

Thus, even if the intervention was successful in the sense that both resistant and improved readers enhanced their phonological awareness more than the two control groups, only improved readers seemed to be able to transfer this improvement to their reading.

To further explore potential individual differences, we examined how phonological and orthographic word decoding skills were related to reading ability for

TABLE III. Relative contribution (β) of orthographic and phonological decoding skills on reading skill in test sessions 1–3 for improved readers ($n = 17$), resistant readers ($n = 16$), Grade 4 controls ($n = 16$) and Grade 2 controls ($n = 16$)

	Improved readers	Resistant readers	Grade 4 controls	Grade 2 controls
Test session 1, December 1994				
Orthographic	0.57[1]	0.85[1]	0.69[1]	0.21
Phonological	0.43[1]	− 0.04	0.39[1]	0.68[1]
Test session 2, May 1995				
Orthographic	0.66[1]	0.60[1]	0.57[1]	0.46[1]
Phonological	0.37[1]	− 0.10	0.47[1]	0.55[1]
Test session 3, December 1995				
Orthographic	0.44[1]	0.87[1]	0.34[1]	0.46[1]
Phonological	0.66[1]	− 0.02	0.62[1]	0.55[1]

[1]Significant prediction of text reading skill ($p < 0.05$).

resistant and improved readers before, during and after intervention. Twelve separate multiple regression analyses were performed, one for each group in each test session (see Table III). F values varied between 2.90 and 29.0 and multiple R values varied between 0.55 and 0.91, with the exception of the analysis of Grade 4 controls in test session 2, where $F = 1.48$ and multiple $R = 0.45$.

These results are quite consistent. Both orthographic and phonological word decoding skills predicted text reading ability for improved readers. The same pattern of results was found for Grade 4 controls. On the other hand, only orthographic word decoding skills predicted reading ability for resistant readers. For Grade 2 controls, only phonological word decoding predicted text reading ability initially, whereas both decoding strategies were related to reading ability in test sessions 2 and 3. The results were not simply due to a lower variation in the scores of the resistant readers (standard deviations were comparable; see Table II).

GENERAL DISCUSSION

First, it is important to note that the results are in accordance with the previous findings that phonological training enhances the phonological awareness of young children (Lundberg *et al.*, 1988; Hatcher *et al.*, 1994). However, the present study demonstrates that it is by no means certain that an improvement in phonological awareness is accompanied by an improved reading skill (cf. Wise & Olson, 1995; Olson *et al.*, 1997; Torgesen *et al.*, 1997). Despite the fact that the resistant readers steadily increased their phonological awareness during the intervention, this had a very limited effect on their reading achievement. These results might support previous findings indicating that phonological awareness is necessary but not sufficient for the development of word decoding skills (Tunmer *et al.*, 1988; Byrne & Fielding-Barnsley, 1989; Byrne *et al.*, 1992).

The results of the present study indicate that a training programme focusing on phonological awareness is only moderately successful for children who have received formal reading instruction in school for several years and still have not achieved satisfactory reading skills. The question then is what are the differences between a group of kindergarten children, who might benefit more from phonological awareness training (Ball & Blachman, 1988, 1991; Lundberg *et al.*, 1988) compared with 10–11-year-old poor readers who, on average, do not seem to benefit very much? First, it is important to point out that the children in our study have demonstrated that they have lasting reading difficulties. In general, the 'hard core' of reading-disabled children, including developmental dyslexics, would be expected to remain in the group still needing special instruction in Grade 4 (Lundberg, 1984; Stanovich, 1986; Juel, 1988). Olson and colleagues (Wise & Olson, 1995; Olson *et al.*, 1997) have studied the effects of various types of individual, computer-assisted instruction for groups of poor readers (on average 9 years of age) and conclude that specific positive effects, reflecting the different training conditions, are obtained but that there is very limited transfer to their word decoding and reading skills (see also Van der Leij, 1994; Torgesen *et al.*, 1997). These results support the expressed view of Stanovich (1986) that lower level deficits in poor readers are difficult to treat at a relatively late age. In the present study we provide a possible explanation of the limited transfer between a growth in phonological awareness and reading ability, which might have to do with another potential difference between children in Grade 4 and kindergarten children: that one would expect to find more developed strategies for dealing with written language in the older group. Thus, phonological awareness training might serve as an introduction to reading instruction for kindergarten children, whereas for children in Grade 4 phonological awareness training has to be integrated with the participants' existing word decoding strategies.

The main difference between improved and resistant readers was that only orthographic word decoding predicted text reading performance for resistant readers (see Table III). A hypothesis stemming from this result might be that the phonological training might have interfered with the more visually based strategy already in place. Phonological awareness training could be expected to have only limited effects on visual/orthographic decoding skills and, therefore, the observed improvement in phonological awareness might not have transferred to an improved text reading ability for resistant children. If these children mostly rely on orthographic word decoding, perhaps reading instruction should be better matched with what they are already attempting to do when reading. In this sense, our results might be in line with the intervention studies emphasising explicit linkages between phonology and letters (Bradley & Bryant, 1983; Cunningham, 1990; Hatcher *et al.*, 1994). It is possible that more explicit instructions concerning letter–sound correspondences might be required to mediate progress in reading for resistant children.

The improved group enhanced their text reading skills just as much as did the Grade 2 controls (see Table II). This might be regarded as a positive result when the very different initial status of the children in these two groups is considered. The improved group consisted of children 10–11 years old who still needed special instruction because of severe reading difficulties. The Grade 2 controls, on the other

hand, were normal readers but 2 years younger, and substantial improvements in their reading skills would be expected during the following year. Thus, strictly phonological training might be effective for some upper primary poor readers who, to some extent, seem to rely on phonological word decoding (see Table III). Still, it remains to be examined whether these children would also benefit from combining phonological training with linkage activities in reading instruction (cf. Hatcher *et al.*, 1994).

The present study calls attention to the need to apply an individual difference perspective when planning and implementing a phonological training programme for poor readers. The results presented in Table III specifically suggest that in order to detect children who might resist improving their reading skill by means of phonological awareness instruction, one ought to assess their reliance on orthographic or phonological word decoding, respectively. Failure to do so may unnecessarily jeopardise their reading development.

Limitations of the Study

In a field experiment such as this the ideal experimental design often cannot be attained (for a review see Troia, 1999). One limitation of the present study was lack of control of a potential teacher effect (cf. Lundberg *et al.*, 1988). There were different teachers in the experimental condition and the Grade 4 control condition. The fact that there were several teachers in each condition (nine in the experimental condition and five in the Grade 4 control condition) reduces this problem somewhat, but we cannot completely rule out that the teachers in the two conditions differed in their approach to the training beyond the fact that they used different training methods. Also, the same teachers who developed the training programme later used it in the experimental condition. This could perhaps lead to them expending more effort in their teaching than the other five teachers in the Grade 4 control condition. However, even if there was a teacher effect, this would not challenge the findings of this study that individual differences in word decoding strategies might, to some extent, explain why some children benefit from while others resist phonological intervention.

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